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WHITE OAK LABORATORY

SENSOR POSITION LOCATOR

BY
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A remote acoustic sensor, capable of reporting bearing information on targets it hears, may be deployed in the field without the knowledge of its exact location. This report develops an algorithm which calculates the sensor position through use of the bearing reports from a moving target whose location is known as a function of time. A math model along with FORTRAN listings and simulation runs are included.

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PREFACE

This report documents a portion of the work performed at the Naval Surface Weapons Center, White Oak, Silver Spring, Maryland on the Multiple Target Classification and Location task for the REMBASS Advanced Development under Agreement Number 75-14.

C. A. Fisher
C. A. FISHER
By direction

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Chapter 1

INTRODUCTION

Remote unattended ground sensors are being developed which have the capability of passively determining the bearing angle of the targets they detect and reporting this information in real time to a central location via an RF link. For one reason or another, it is not always known just where the reporting sensors are located in an exact geographical sense. Although each sensor possesses a unique identifier in the message code transmitted, the original emplacement of a sensor field may not be done by surveying them in, but rather by dropping them out of aircraft, or using rocket or gun delivery.

The purpose of this task has been to determine the location of such sensors after they have been emplanted. The proposed method is to move a target, whose location as a function of time is known, over the sensor field. The sensors will each report the bearing angle of the target several times as the target passes by. Since the target is moving, each report by a sensor will (usually) be somewhat different. That is, the sensor will report a series of angular measurements, which will differ as the target changes location. By knowing the target location as a function of time back at the sensor reporting unit the present algorithm will use the series of reports to calculate the sensor position. The method used constructs radials from the target's position towards the sensor. Each of the many radials should intersect at the sensor position, as shown in Figure 1.

A weighted least-squares algorithm is used to fit the lines to the point which represents the sensor position. This theory is relatively simple, but there are problems which complicate the calculations.

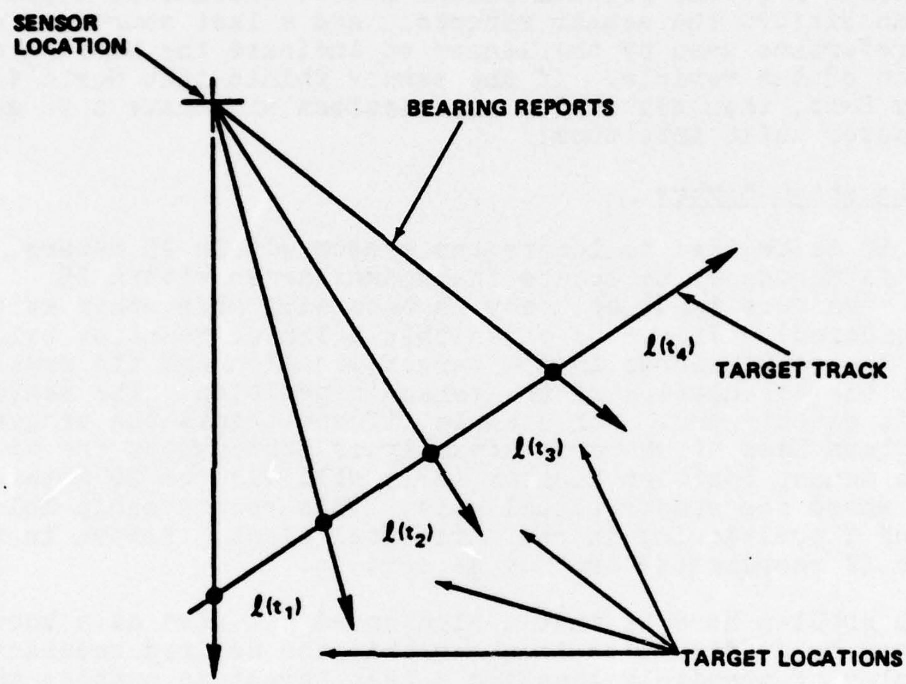


FIG. 1 SENSOR FIELD

Chapter 2

PROBLEMS AND SOLUTIONS

As stated there are several factors which complicate the calculation of a sensor's position. One of these is the uncertainty of the location and speed of the "known" target used to locate the sensor. A second problem occurs due to extraneous noise sources which can distort the sensor reports. And a last source of error is the reference used by the sensor to indicate the bearing or direction of the vehicle. If the sensor thinks that North is actually East, then all of its calculations will have a 90 degree error factor built into them.

Target Location Errors

If it is desired to locate the sensor within 25 meters, then it is necessary to locate the known target within 25 meters (even more input accuracy is necessary when other errors are considered). It can be shown that a linear relation exists between the planar error in the target location and the resulting error in the calculation of the sensor's position. The scale factor is exactly one. For example, if one thinks the target is 20 meters East of where it actually is (throughout the track) then the Sensor Position Locator (SPL) will also be 20 meters East of where the sensor actually is. This relationship holds for X and Y positioning in the horizontal plane. Errors in the altitude (Z coordinate) are not as serious.

The problem here is that a high speed jet used as a known target may be difficult to locate within the desired accuracy. The problem of precisely locating a test target is outside the scope of this investigation, but the errors it causes are not. It is evident that the available accuracy for sensor position location is determined by the current capabilities of target position location for cooperating targets.

Sensor Report Errors

At the time of investigation, the sensors themselves are also under development. It is not known exactly what kind of accuracy these sensors will have, and the bearing values reported

by the sensors have to be believed, to some extent, as the truth. Therefore, errors originating in the sensor will propagate to the SPL algorithm. It is not the purpose of this task to reduce these inherent sensor errors, but rather to reduce the propagation of these errors to the greatest possible extent. Associated with these "sensor errors" are errors caused by other noise sources in the environment.

It is assumed that the magnitude of the error does fluctuate and the simulation in this work has used gaussian noise as an error model. It is reasonable to try to catch and use the data when it is close to error-free and ignore the data when it is believed to contain large errors. The problem is therefore to find some indicator to tell us of the magnitude of the error, and such indicators do exist. Possibilities include signal to noise ratio, signal strength, and distance from the sensor to the target. The first and last of these indicators were used in the simulation and favorable results were obtained.

The least-squares algorithm will accept a weighting factor (W) based on data quality and it appears that full use of it will improve the quality of the SPL.

Because of the multi-pass SPL algorithm, it is possible to estimate the radial distance from the sensor to the target, and then use it to construct a weighting factor within the algorithm itself. This too has been done in the simulation and improvements were noted.

Sensor Rotation Error

In addition to assuming that the sensor will fall in an arbitrary (X, Y) position, it is also assumed that the sensor will have an arbitrary angular orientation. When the sensor reports, "I see a target at 90 degrees," does that mean North, East, South, or West?

It is probable that each sensor will ultimately contain its own compass, in which case, this source of error would be minimized. It seems reasonable that errors in angular orientation calculated inside the sensor might be on the order of five degrees, when one considers that the compass will be in close proximity to metal parts of the sensor, etc. This amount of angler error, called angle bias, can produce very unsatisfactory errors in the SPL

simulations (on the order of hundreds of meters). Therefore, it seems necessary to include a bias calculation within the SPL algorithm. Fortunately, it is possible to calculate the angle bias without knowing the sensor position, and the latter can then be determined using this bias for compensation.

Errors in the SPL simulation due to all of these sources are discussed in more detail in Appendix A.

Chapter 3

MATH MODEL FOR CALCULATION OF ROTATION BIAS

This is a straightforward algorithm that uses three bearing reports ($\alpha 1$, $\alpha 2$, $\alpha 3$) that all have the same bias. It is not necessary that the reports be sequential, and in fact if there are many reports which differ only slightly in bearing, then it is advisable not to use sequential reports because they will probably be in the same or adjacent bearing bin. The algorithm uses angle differences in which the bias subtracts out and, using the geometry of adjacent triangles, calculates an internal angle which in turn leads to the bias. The algorithm will not work if the angle differences are zero which occurs if the target has not moved.

Figure 2 shows the geometry necessary for the calculation of the rotational bias of the sensor. If the sensor reports the three angular bearings ($\alpha 1$, $\alpha 2$, $\alpha 3$) shown in Figure 2, then d_{12} and d_{23} are the linear distances along the target track between those reports. α_A is the direction of the target track with respect to North. By applying the law of sines to Figure 2 one obtains equations 1 and 2 and by also applying Figure 2, the law that the sum of the interior angles of a triangle is 180 degrees, one obtains equations 3 and 4.

$$\frac{d_{12}}{\text{Sin }\theta_1} = \frac{d_{S2}}{\text{Sin A}} \tag{1}$$

$$\frac{d_{23}}{\text{Sin }\theta_2} = \frac{d_{S2}}{\text{Sin D}} \tag{2}$$

$$\theta_1 + \theta_2 + A + D = \tag{3}$$

$$\alpha_A + (\pi - A) + (\pi - \text{Bias} - \alpha_1) = \pi \tag{4}$$

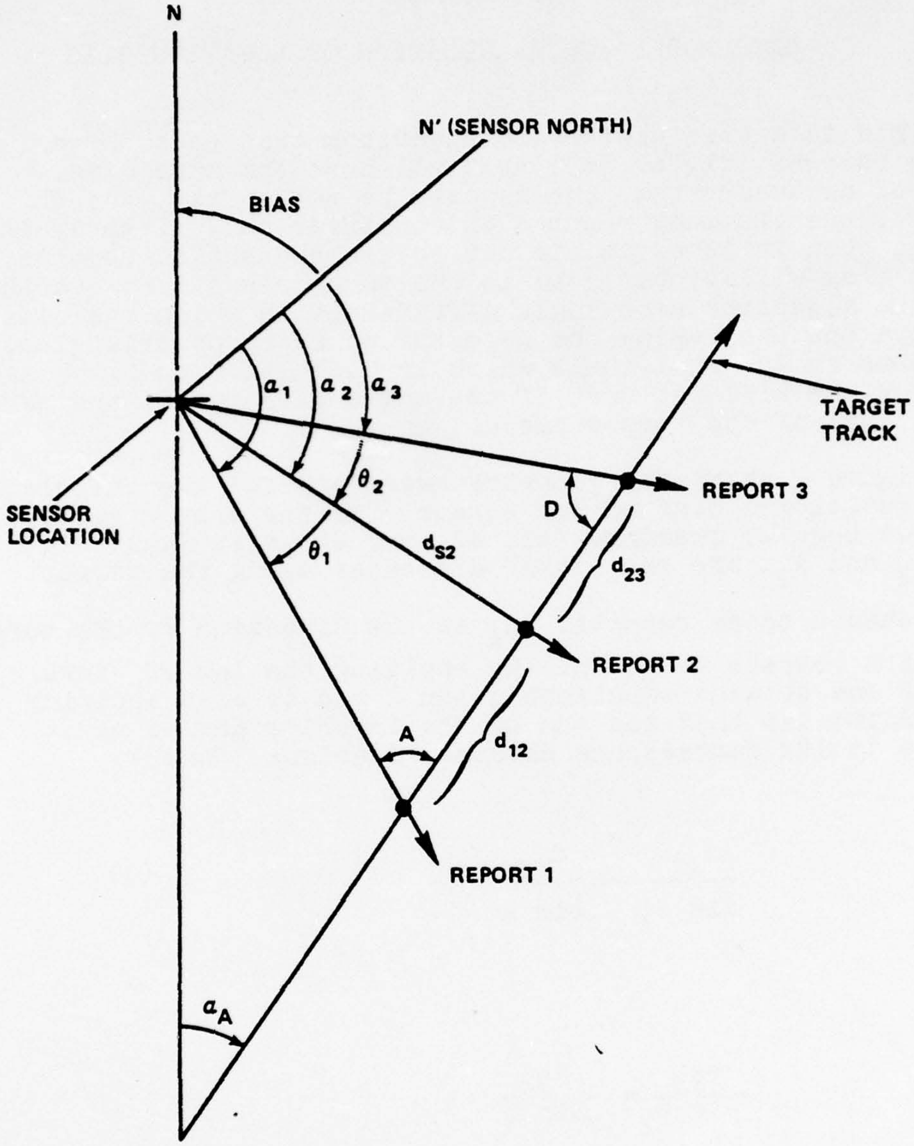


FIG. 2 BIAS CALCULATION - TRIANGLES

Eliminating d_{S2} from equations 1 and 2 yields:

$$d_{12}\,\frac{\sin A}{\sin \theta_1} = d_{23}\,\frac{\sin D}{\sin \theta_2} \tag{5}$$

Using equations 3 and 5 to eliminate D and then solving for A one finds:

$$A = \arctan\left[\frac{\sin(\theta_1 + \theta_2)}{\frac{d_{12}}{d_{23}} \bullet \left(\frac{\sin\theta_2}{\sin \theta_1}\right) - \cos(\theta_1 + \theta_2)}\right] \tag{6}$$

$$\text{where } \theta_1 = (\alpha_1 - \alpha_2)$$
$$\theta_2 = (\alpha_2 - \alpha_3)$$

Equation 4 can be rewritten to solve for the rotational bias:

$$\text{BIAS} = \pi + \alpha_A - \alpha_1 - A \tag{7}$$

Referring to Figure 2, it is possible for the rotational bias to be in the other direction. That is, for the line N' to be on the other side of N. If this is the case, the rotational bias from equation 7 will turn out to be negative.

Least Squares Method for Bias Calculation

Due to the inherent errors in any system, the results achieved by this calculation of the rotational bias will be in error by some amount. If one was to perform this calculation several times for different target runs one would get several values for the rotational bias, called B_i. Assuming the errors are gaussian, a best value for the rotational bias would be the mean and an indication of the accuracy of that value would be the standard deviation. If some values are known to be more accurate than others, they can be multiplied by some weighting factor, W_i, to yield better results. Then the final value for the bias would be:

$$\text{BIAS} = \frac{\sum\limits_{i-1}^{n} (W_i B_i)}{\sum\limits_{i=1}^{n} (W_i)} \qquad (8)$$

The standard deviation for this BIAS calculation is:

$$\sigma = \frac{\sum\limits_{i=1}^{n} W_i (B_i^2 - \text{BIAS}^2)^{1/2}}{\sum\limits_{i=1}^{n} W_i} \qquad (9)$$

Effects of the Speed of Sound

It is easily observed, when listening to an approaching high-speed target, that the target is ahead of the incoming sound waves. This is because the sound takes a finite Δt seconds to travel from the target to the observer. In this Δt seconds the target moves, and is therefore ahead of where it was when the sound originated.

The point is to determine the effect of this error on the calculation of the rotational bias and to correct for it. In two dimensions this error can be deterministically calculated independent of radial distance and therefore can be calculated without knowing the sensor's location.

Correction Algorithm. Let Δt be the time elapsed between the time when the sound originated at the target (t_1) and the time when the sound is received at the sensor (t_2). Figure 3 depicts this case where C is the speed of sound, V is the velocity of the target, C (Δt) is the distance from the sensor to the target at time t_1, V(Δt) is the distance the target will travel in the time Δt, α_A is the target course, θ is the angular error due to the speed of sound, and αt_1 is the report vector referenced to true North (not sensor North). Applying the law of signs (equation 12) and the sum of the interior angles of a triangle equals 180 degrees (equations 10 and 11) to Figure 3 yields:

$$(180 - \alpha_{t1}) + (180 - \beta) + \alpha_A = 180° \qquad (10)$$

$$\gamma = 180° - \theta - \beta \qquad (11)$$

$$\frac{C(\Delta t)}{\text{Sin } \gamma} = \frac{V(\Delta t)}{\text{Sin } \theta} \qquad (12)$$

Substituting from equation 11 into equation 12 and simplifying gives the error due to the speed of sound, θ, to be:

$$\theta = \arctan \frac{\text{Sin } \beta}{\frac{C}{V} - \cos \beta} \qquad (13)$$

And from equation (10) we find B is:

$$\beta = 180 - \alpha_{t1} = \alpha_A$$

= 180 degrees - report bearing referenced to true North + target course.

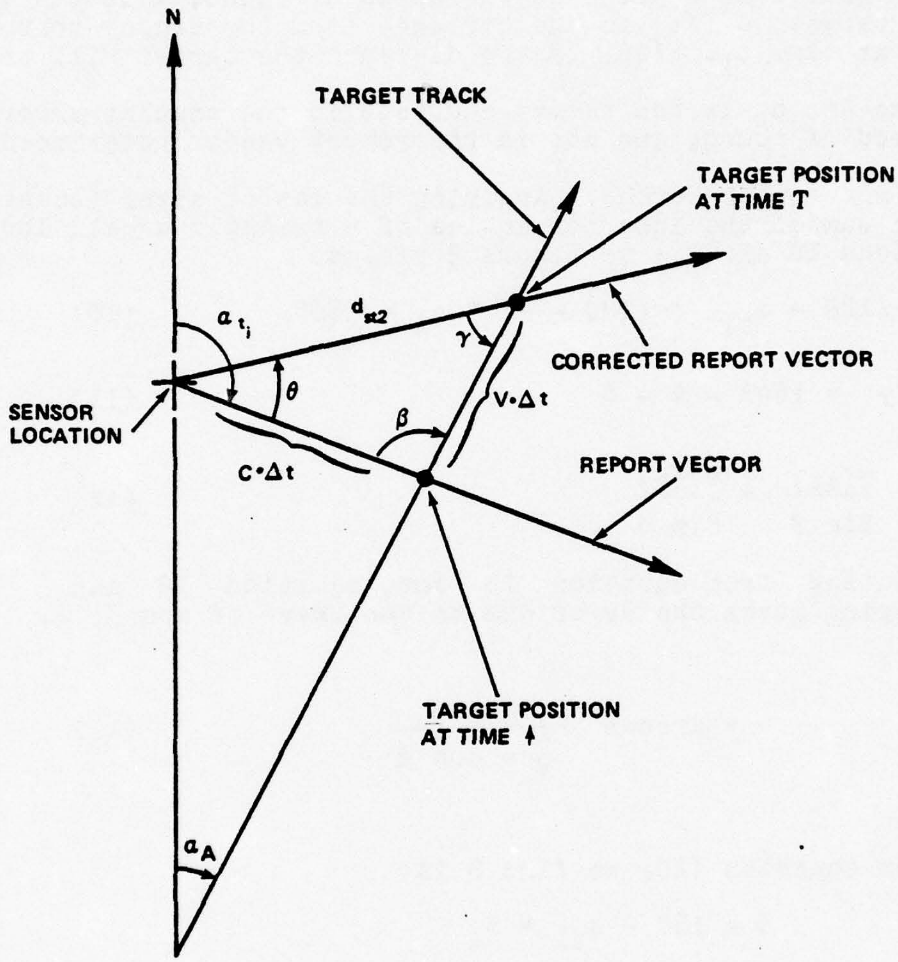


FIG. 3 SPEED OF SOUND CORRECTION IN 2-D

Figure 4 gives the correction angles for some values of B and V/C. As an example, if the target were reported such that B = 60 degrees and the velocity was 300 mph, or V/C = 0.4; then the target would really be 23 degrees ahead of the report bearing.

Adjustments for 3-D. The previous discussions were all done in a two dimensional space, that is for the target track in the same plane as the sensor. To extend the algorithm to three dimensions will require the following simplifying assumptions; (1) that the target will travel in a horizontal plane parallel to the ground plane, (2) that the sensor will report in the ground plane as if the target were also in the ground plane, and (3) that the altitude of the sensor, Z0, will be assumed to be zero. Thus the altitude of the target, ZA, is just the perpendicular distance between the two parallel planes. Figure 5 depicts these assumptions.

Correction Due to Speed of Sound in 3-D. In 2-D the correction error, θ, due to the speed of sound is independent of the horizontal distance from the sensor to the target track. Unfortunately, this is not true if there is a sizable altitude difference between the target track and the sensor.

Since θ is needed to calculate the sensor location and the sensor location is needed to calculate the altitude correction to θ, an iterative algorithm must be used whereby the sensor location is first calculated without the altitude correction for θ. This sensor location is then used to determine a more accurate value for θ, this new value of θ is used to generate an improved sensor location, and so forth until the desired accuracy is achieved.

Figure 6 shows the speed of sound correction for three dimensions where ZA is the perpendicular distance between the target plane and the sensor plane, $RXYT_1$ is the distance from the sensor to the projection of the target onto the sensor plane at time t_1, and θ is the correction error due to the speed of sound. Note that both γ and θ are in the ground plane.

The calculations for the three dimensional case are very similar to those for the two dimensional case. In fact, equations 10 and 11 still hold. However, equation 12 now reads:

$$\frac{RXYT_1}{\text{Sin }\gamma} = \frac{(V)\ (\Delta t)}{\text{Sin }\theta} \qquad (15)$$

V/C OR RATIO	.9	.8	.7	.6	.5	.4	.3	.2	.1	.05	.025	.0125	0
ANGLE β / MPH	675	600	525	450	375	300	225	150	75	37.5	18.8	9.4	0
M/S	302	268	235	201	168	134	101	67	34	17	8.4	4.2	0
180°	0°	0°	0°	0°	0°	0°	0°	0°	0°	0°	0°	0°	0°
150°	14°	13°	12°	11°	10°	8°	7°	5°	3°	1°	1°	0°	0°
135°	21°	20°	18°	17°	15°	12°	10°	7°	4°	2°	1°	1°	0°
120°	32°	26°	24°	22°	19°	16°	13°	9°	5°	2°	1°	1°	0°
90°	42°	39°	35°	31°	27°	22°	17°	11°	6°	3°	1°	1°	0°
60°	55°	49°	43°	37°	30°	23°	17°	11°	5°	3°	1°	1°	0°
45°	60°	52°	44°	36°	27°	22°	15°	9°	4°	2°	1°	1°	0°
30°	64°	52°	42°	32°	24°	17°	11°	7°	3°	1°	1°	0°	0°
10°	54°	33°	21°	14°	10°	7°	4°	2°	1°	1°	0°	0°	0°
0°	0°	0°	0°	0°	0°	0°	0°	0°	0°	0°	0°	0°	0°

FIG. 4 SAMPLE BEARING ERROR DUE TO THE SPEED OF SOUND

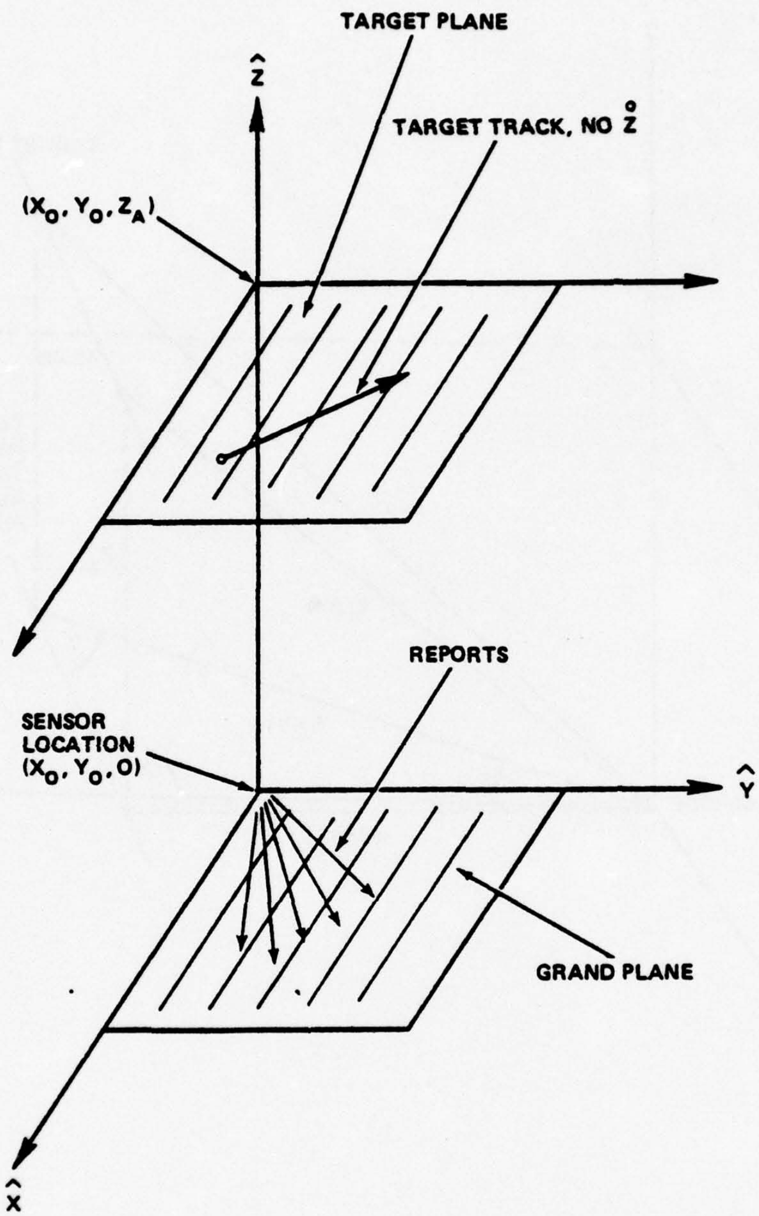


FIG. 5 ASSUMPTIONS IN THE 3-D MODEL

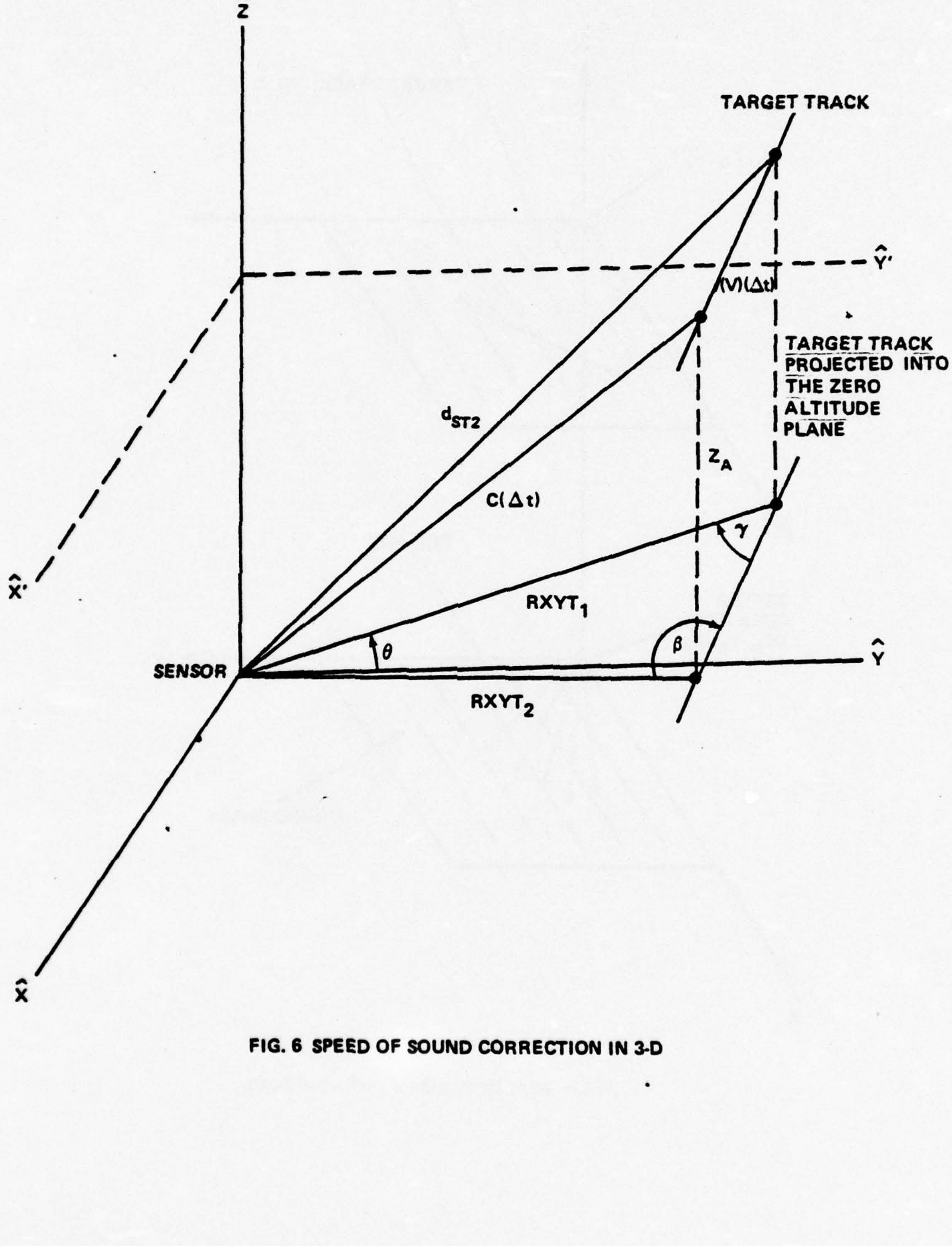


FIG. 6 SPEED OF SOUND CORRECTION IN 3-D

Observe that the projection of the line (C) (Δt) onto the sensor plane forms a right triangle. This gives one a relationship between equations 12 and 15, namely:

$$(C)\ (\Delta t) = \sqrt{(ZA)^2 + (RXTT_1)^2} \tag{16}$$

Let

$$\text{Ratio} = \left(\frac{C}{V}\right) \left(\frac{1}{\sqrt{1 = (ZA/RXYT_1)^2}}\right) \tag{17}$$

Then equation 13 for the three dimensional case becomes:

$$\theta = \arctan \frac{\text{Sin}\ \beta}{\text{Ratio} - \cos \beta} \tag{18}$$

Unfortunately, to calculate θ, one needs to know $RXYT_1$ (equation 17), and $RXYT_1$ is dependent upon the sensor location.

Calculating $RXYT_1$. Chapter 4 discusses the sensor position. Once this is done one can come back and calculate $RXYT_1$.

Figure 7 is a two dimensional view of the ground plane of the three dimensional speed of sound correction shown in Figure 6. β is defined by equation 14, θ is the correction error due to the speed of sound, and $RXYT_1$ and $RXYT_2$ are the projections of (C)(Δt) and (d_{st2}) onto the sensor plane.

From the definition of the sine of a right triangle it is seen from Figure 7 that:

$$RXYT_1 = \frac{\sqrt{(X_0 - X_p)^2 + (Y_0 - Y_p)^2}}{\text{Sin}\ \beta} \tag{19}$$

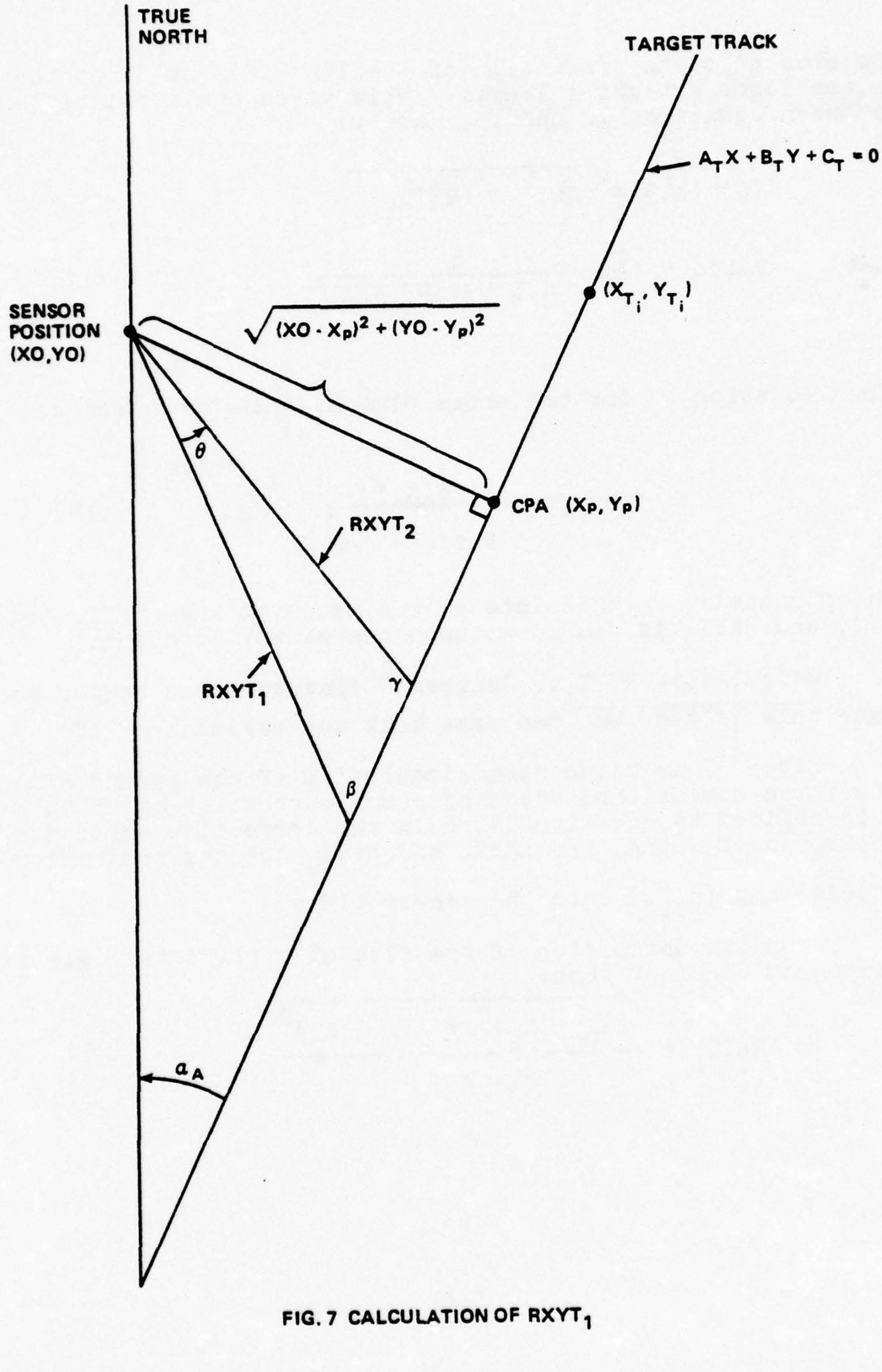


FIG. 7 CALCULATION OF $RXYT_1$

The value $\sqrt{(X_0 - Y_p)^2 + (Y_0 - Y_p)^2}$ is simply the distance between the two points (X_0, Y_0) and (X_p, Y_p). The point (X_0, Y_0) is the sensor location which is calculated in Chapter 4. The other point (X_p, Y_p) is calculated as the point on the target track closest to the sensor.

The equation of the line $(A_T X + B_T Y + C_T = 0)$ can be found from any point (X_{T_i}, Y_{T_i}) on that line and from the slope (α_A) of that line. From standard algebraic formulas:

$$A_T = \cos(\alpha_A) \tag{20}$$

$$B_T = \sin(\alpha_A) \tag{21}$$

$$C_T = A_T X_{T_i} - B_T Y_{T_i} \tag{22}$$

The co-ordinates of the point (X_p, Y_p) on the line $A_T X + B_T Y + C_T = 0$ that is closest to the point (X_0, Y_0) is given by:

$$X_p = \frac{-(A_T C_T + B_T X_0)}{(A_T{}^2 + B_T{}^2)} \tag{23}$$

$$Y_p = \frac{A_T(A_T Y_0 - B_T X_0) - B_T C_T}{(A_T{}^2 + B_T{}^2)} \tag{24}$$

Now $RXYT_1$ (equation 19) can be calculated and substituted into equations 17 and 18.

Chapter 4

CALCULATION OF SENSOR POSITION

At this point it is assumed that the reported bearing has been corrected and that it points from the sensor to the target at time t_2. The method of approach is to calculate the parameters of a line, $L_i = a_i x + b_i y + c_i$, passing through the target and along the reported bearing ray. This is done for every report. Therefore, many lines will be calculated, all of which should intersect at the sensor's position. Because of the inaccuracies in the bearing report and in the target's position it is not expected that every line will intersect exactly at the sensor's position. Figure 8 shows a typical case.

The idea is to find a point (X_0, Y_0) which best fits the intersection of all the lines. A weighted least-squares algorithm is used, and the distance function is the ratio of the perpendicular distance, d, from the point (X_0, Y_0) to each line over the radial distance, rxy, (where rxy is equivalent to $RXYT_2$ in Figure 6) from the target to the sensor. This ratio is the arc sine of theta, Θ_i, as shown in Figure 9 for one bearing report. For small Θ,

$$\Theta_i = \frac{d_i}{rxy_i} \tag{25}$$

Math Model for SPL

The weighted least-squares algorithm to be used requires minimizing the equation below where W_i is a weighting function:

$$S = \sum_{i=1}^{n} W_i (\Theta_i)^2 \tag{26}$$

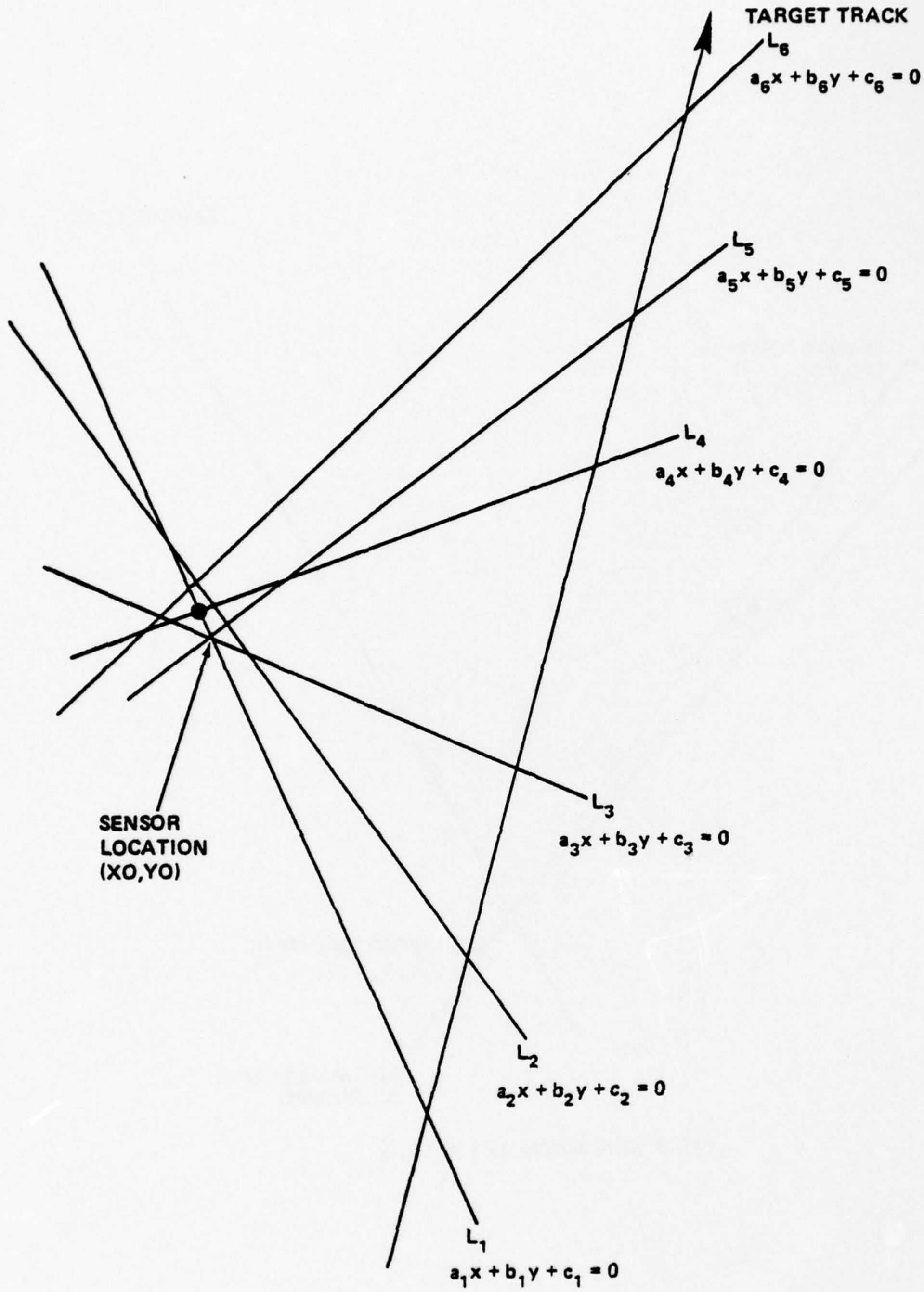


FIG. 8 SENSOR POSITION LOCATOR

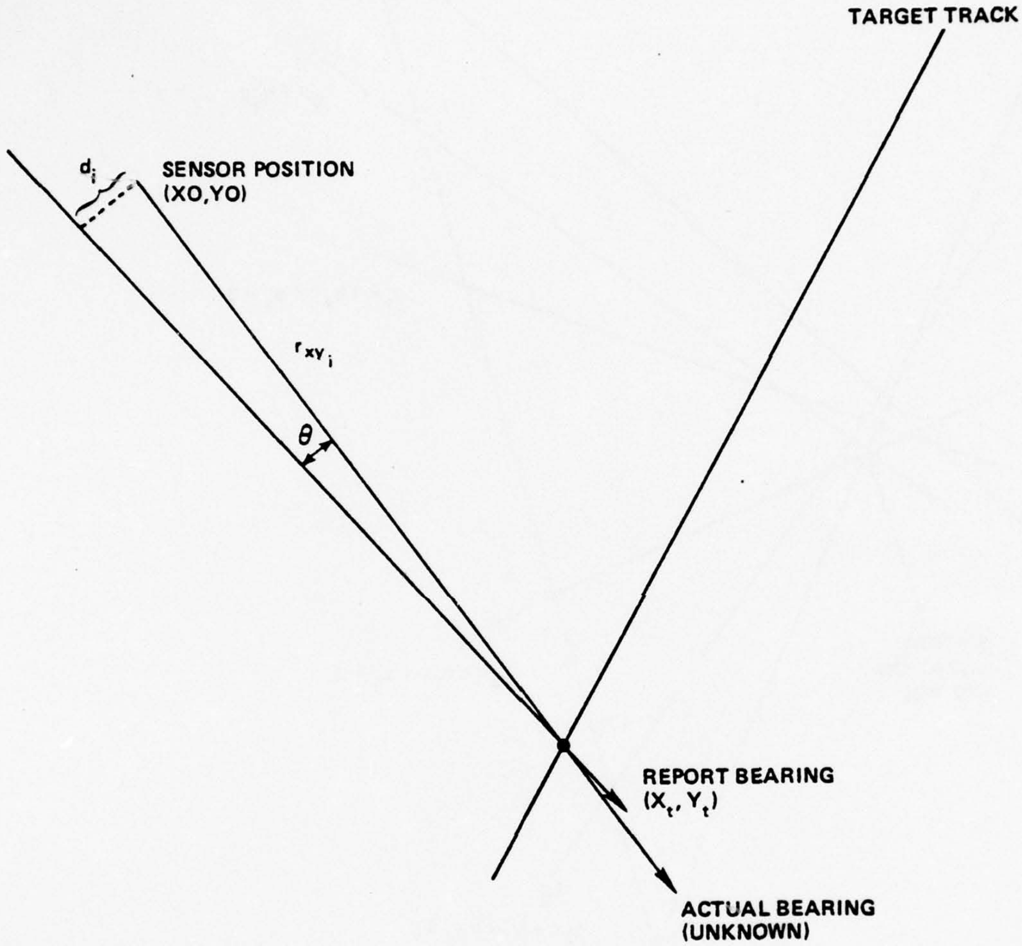


FIG. 9 DEFINITION OF THETA, θ

The distance from the sensor location, point (X_0, Y_0), to the line L_i is given by:

$$d_i = \left| \frac{a_i X_0 = b_i Y_0 + C_i}{a_i^2 + b_i^2} \right| \quad (27)$$

The length of the line rxy_i is given below where (X_0, Y_0) is the sensor location and (X_{Ti}, Y_{Ti}) is the i^{th} target location.

$$rxy_i = \sqrt{(X_0 - X_{Ti})^2 + (Y_0 - Y_{Ti})^2} \quad (28)$$

Substituting equations 25 and 27 into equation 26, one gets:

$$S = \sum_{i=1}^{n} \frac{W_i (a_i X_0 + b_i Y_0 + C_i)^2}{(a_i^2 + b_i^2)\,(rxy_i)^2} \quad (29)$$

To minimize equation 29 one needs to take the partials with respect to X_0 and Y_0. To simplify these calculations let X_0 and Y_0 in equation 28 be the sensor position from a previous calculation $(\overline{X}_0, \overline{Y}_0)$. Then rxy_i is not a function of X_0 and Y_0 and can be treated as a constant. The above simplifying assumption results in acceptable errors. Without this assumption the model cannot be brought into closed form. A more complex derivation has been worked out but not implemented here. It was abandoned because of the fast growth of complexity with little promise of any accuracy to be gained.

Taking the partials of equation 29 with respect to X_0 and Y_0 and setting them equal to zero gives the following formulas for calculation of X_0 and Y_0:

$$X_0 = \frac{\left(\sum\frac{w_i b_i c_i}{(a_i^2+b_i^2)RXY_i^2}\right)\left(\sum\frac{w_i a_i b_i}{(a_i^2+b_i^2)RXY_i^2}\right)-\left(\sum\frac{w_i a_i c_i}{(a_i^2+b_i^2)RXY_i^2}\right)\left(\sum\frac{w_i b_i^2}{(a_i^2+b_i^2)RXY_i^2}\right)}{\left(\sum\frac{w_i a_i^2}{(a_i^2+b_i^2)RXY_i^2}\right)\left(\sum\frac{w_i b_i^2}{(a_i^2+b_i^2)RXY_i^2}\right)-\left(\sum\frac{w_i a_i b_i}{(a_i^2+b_i^2)RXY_i^2}\right)^2} \tag{30}$$

$$Y_0 = \frac{\left(\sum\frac{w_i a_i c_i}{(a_i^2+b_i^2)RXY_i^2}\right)\left(\sum\frac{w_i a_i b_i}{(a_i^2+b_i^2)RXY_i^2}\right)-\left(\sum\frac{w_i b_i c_i}{(a_i^2+b_i^2)RXY_i^2}\right)\left(\sum\frac{w_i a_i^2}{(a_i^2+b_i^2)RXY_i^2}\right)}{\left(\sum\frac{w_i a_i^2}{(a_i^2+b_i^2)RXY_i^2}\right)\left(\sum\frac{w_i b_i^2}{(a_i^2+b_i^2)RXY_i^2}\right)-\left(\sum\frac{w_i a_i b_i}{(a_i^2+b_i^2)RXY_i^2}\right)^2} \tag{31}$$

Calculation of A_i, B_i, C_i

In order to evaluate equations 30 and 31 one needs to calculate the parameters A_i, B_i, and C_i that form the line $A_i X + B_i Y + C_i = 0$. This line passes through the target position (XT_i, YT_i) and has a corrected report bearing of $d \uparrow c$ as shown in Figure 10. $d \uparrow c$ is just $\alpha t_i - \theta$. Since the slope and one point on a line determine its equation, we find that:

$$A_i = \cos (d \uparrow c) \tag{32}$$

$$B_i = \text{Sin} (d \uparrow c) \tag{33}$$

$$C_i = A_i (XT_i) - B_i (YT_i) \tag{34}$$

Substituting these values and rxy_i (equation 28) into equations 30 and 31 one can solve iteratively for the sensor position (X_0, Y_0). An iterative solution is necessary since rxy_i is calculated using the values of (X_0, Y_0) obtained from the previous iteration.

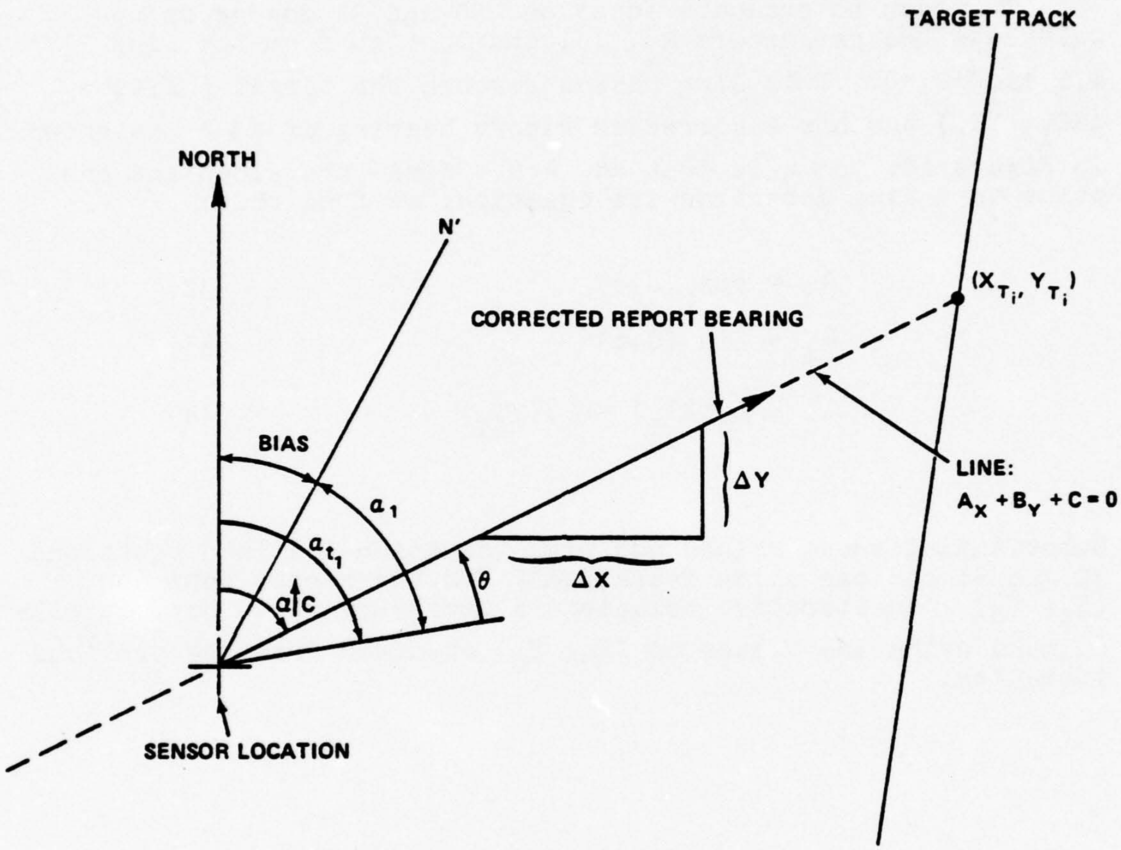


FIG. 10 CALCULATION OF A_i, B_i, C_i

Chapter 5

APPLICATION OF SPL ALGORITHM

To facilitate the calculations involved with the implementation of this algorithm, a computer program was written. This program and the flow charts associated with it are shown in Appendix B.

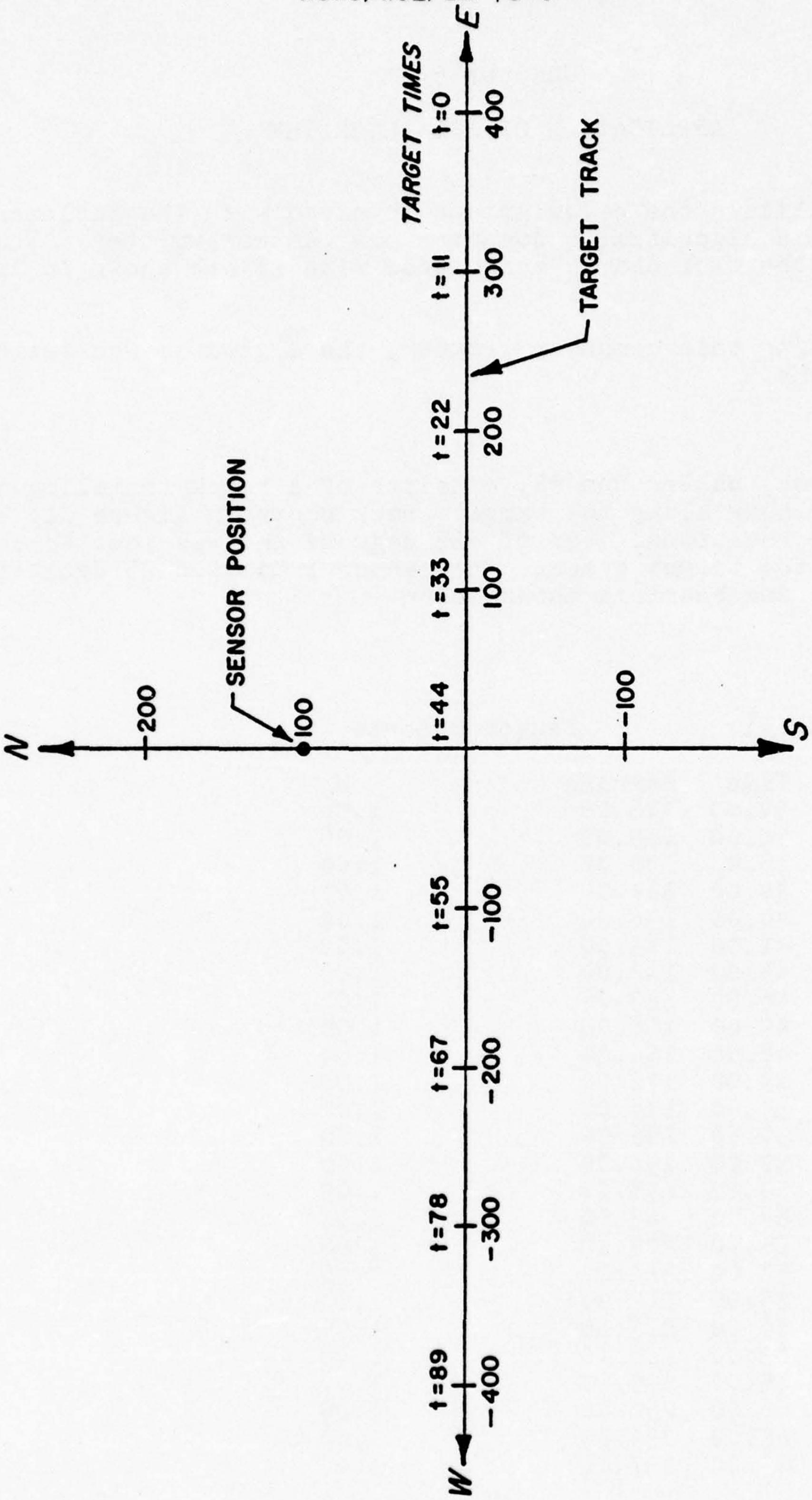
Then using this computer program, the algorithm was tested with two trial runs.

Run #1

The first, called Run #1, consists of a truck traveling at 20 miles per hour along the target track shown in Figure 11. The sensor had a rotational bias of -25 degrees and was located 100 meters from the target track. The sensor indicated 25 detections at the times and bearings shown below.

Run #1 Sensor Reports

Time	Bearing	W
34.00	116.00	1.00
35.00	119.00	1.00
38.00	122.00	1.00
39.00	127.00	1.00
40.00	136.00	1.00
41.00	144.00	1.00
45.00	147.00	1.00
46.00	153.00	1.00
47.00	158.00	1.00
48.00	164.00	1.00
49.00	172.00	1.00
50.00	178.00	1.00
51.00	186.00	1.00
52.00	192.00	1.00
53.00	198.00	1.00
54.00	203.00	1.00
55.00	209.00	1.00
57.00	212.00	1.00
58.00	217.00	1.00
59.00	223.00	1.00
63.00	226.00	1.00
65.00	229.00	1.00
66.00	231.00	1.00
67.00	234.00	1.00
69.00	237.00	1.00



SIMULATED RUN # 1; TARGET TRACK

FIGURE 11

The weighting factor used in the calculations was 1.00 for all points. When the test vehicle passed certain locations along the target track, called stakes, the time was noted. These times and the stake locations are also included in Figure 11.

The sensor position was calculated under three different conditions. For the first case, the rotational bias of the sensor was calculated and this value was used in calculating the location of the sensor. In the other two cases, a value for the rotational bias of the sensor was put into the program and this value was used to calculate the sensor location. The results of these three calculations are shown below where (XO, YO) is the sensor location, Radial error $=\sqrt{(XO)^2 + (YO)^2}$, and ALROT is the sensor angular rotation bias (either calculated or externally set equal to some value.

ROTATIONAL BIAS CALCULATED

	XO	YO	ALROT
REAL	0	100.00000	0
CALCULATED	-38.21974	86.88408	-5.29993
DIFFERENCE	38.21974	13.11592	5.29993
RADIAL ERROR	40.40762		

ROTATIONAL BIAS SET = 0 DEGREES

	XO	YO	ALROT
REAL	0	100.00000	0
CALCULATED	-50.52054	88.81540	0
DIFFERENCE	50.52054	11.18460	0
RADIAL ERROR	51.74380		

ROTATIONAL BIAS SET -25 DEGREES

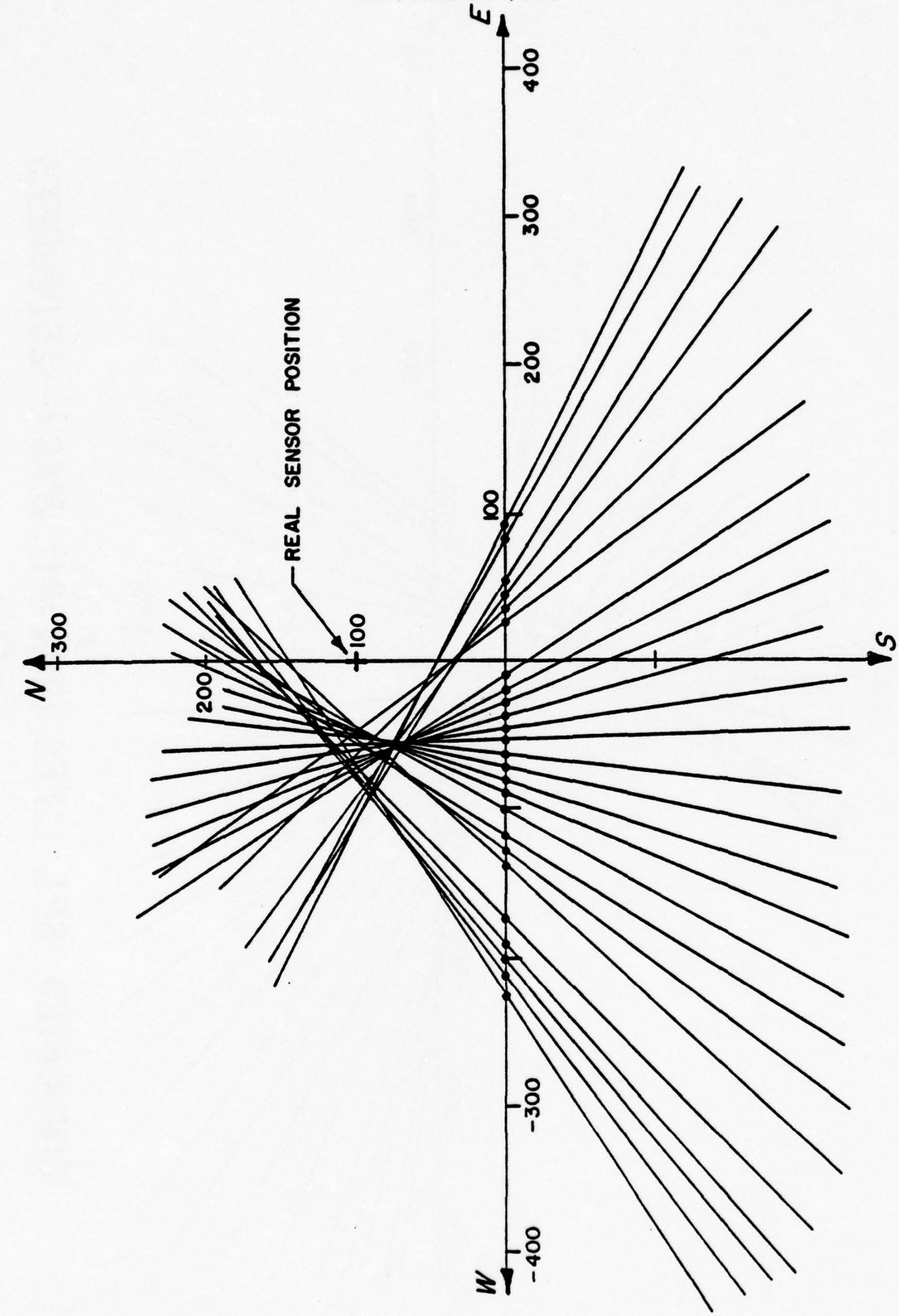
	XO	YO	ALROT
REAL	0	100.00000	-25.00000
CALCULATED	-3.74224	103.15131	-25.00000
DIFFERENCE	3.74224	-3.15131	0
RADIAL ERROR	4.89235		

The Radial Error is lowest for the case where the rotational bias was set at -25 degrees, which indicates that the best results were achieved in this case. This is true because the actual rotational bias of the sensor was -25 degrees.

Figures 12 and 13 graphically depict the two cases where the rotational bias was externally set to either 0 or -25 degrees. In these figures lines were drawn from the vehicle location (whenever the sensor made a report) towards the sensor along a corrected bearing. This corrected bearing was just the bearing reported by the sensor plus 180° minus the rotational bias of the sensor.

Run #2

The second run was very similar to the first. This time a truck was again driven by the sensor at a CPA of 100 meters, and with a velocity of 9 meters/second. However, this time the sensor had a rotation bias of 9 degrees, and the sensor was placed on the other side of the target track. Figure 14 shows the target track and the times that the vehicle passed the different stake locations.



SIMULATED SPL LINES (RUN #1); BIAS = 0 DEGREES

FIGURE 12

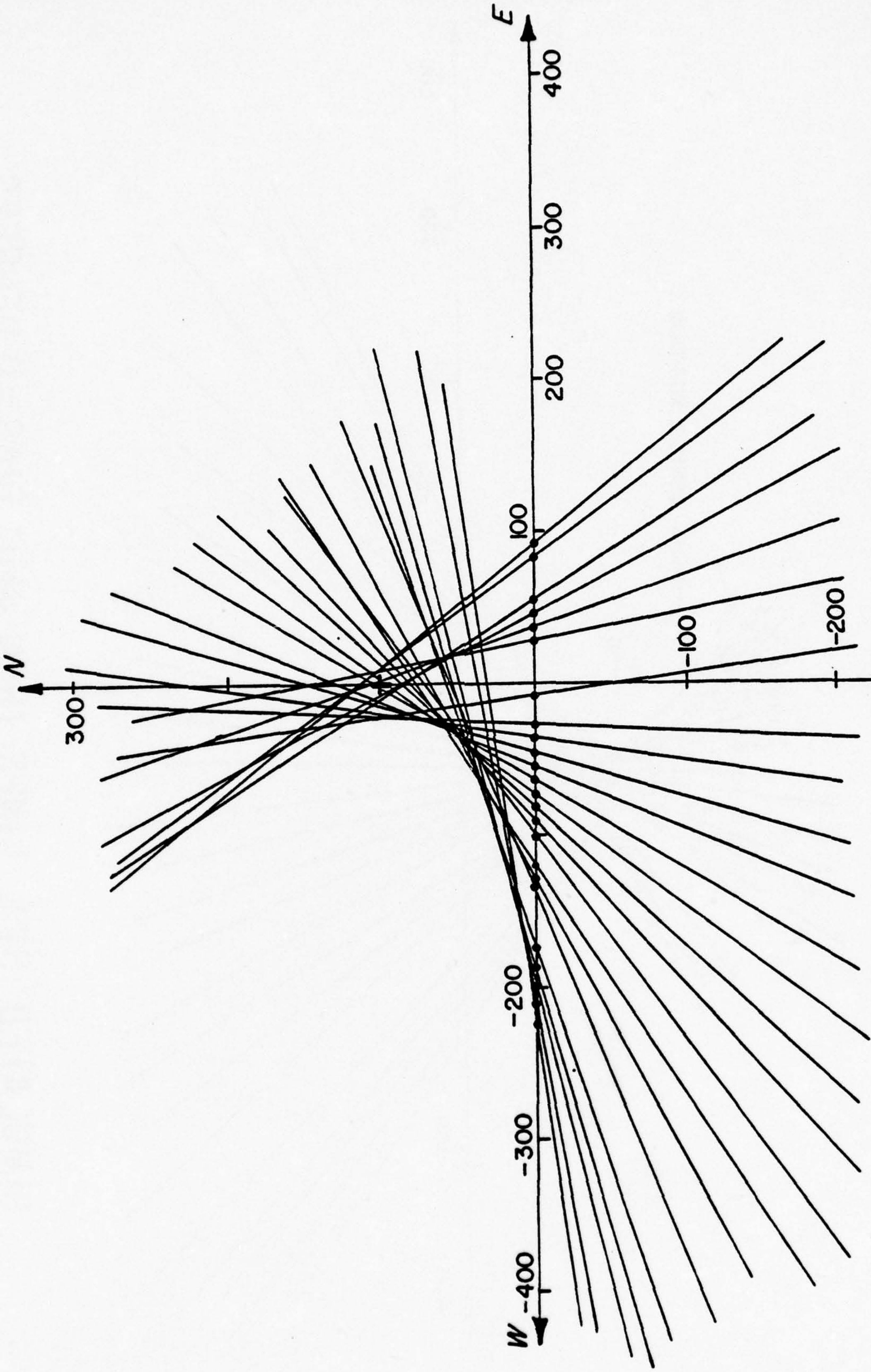
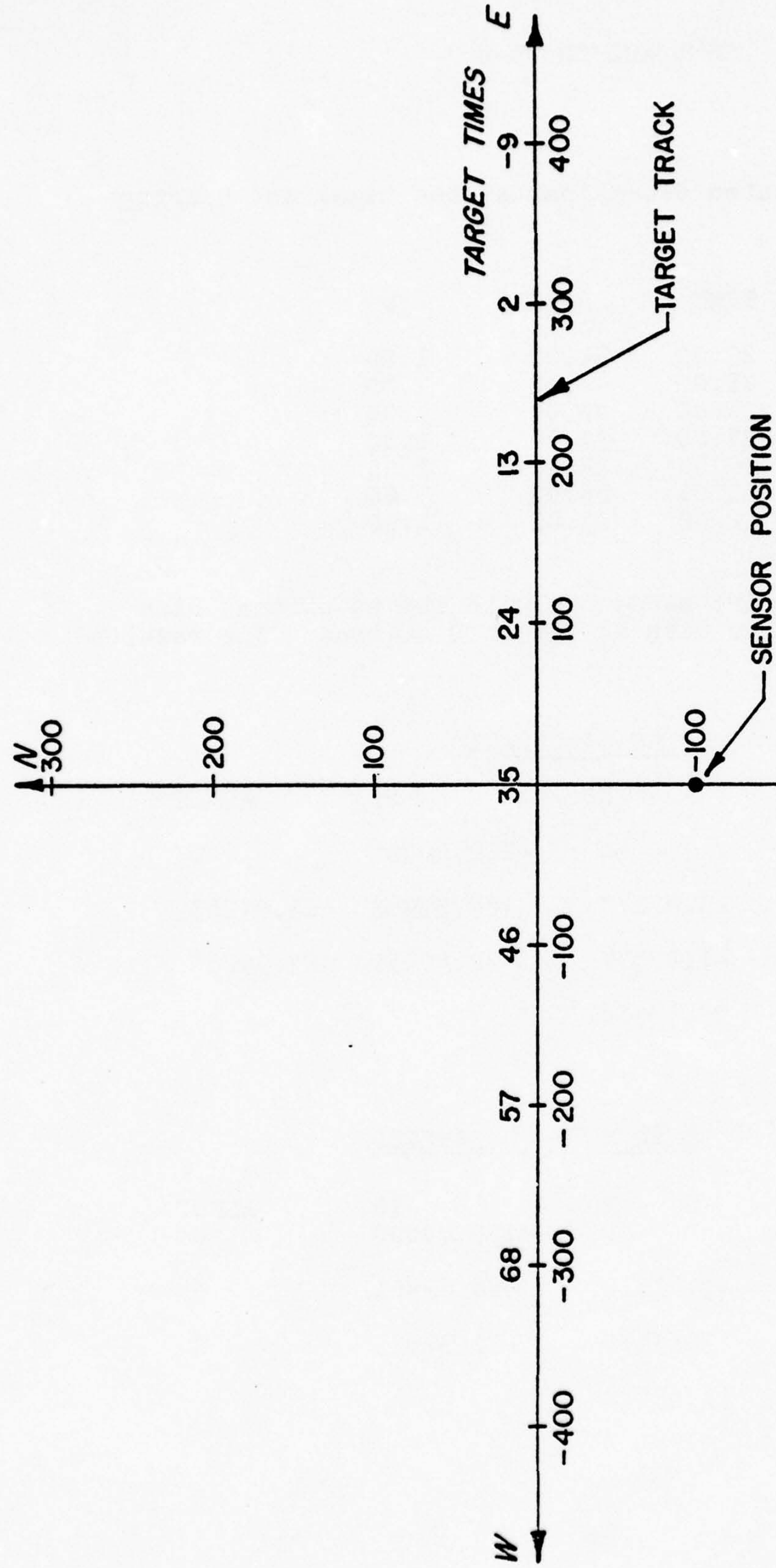


FIGURE 13

SIMULATED SPL LINES (RUN #1); BIAS = −25 DEGREES



SIMULATED RUN#2; TARGET TRACK

FIGURE 14

The sensor indicated detections at the times and bearings shown below.

TIME	BEARING	W
23.00	51.00	1.00
25.00	46.00	1.00
28.00	43.00	1.00
29.00	37.00	1.00
30.00	34.00	1.00
31.00	26.00	1.00
32.00	23.00	1.00

Two SPL calculations were made; one with the rotational bias calculated and the other with it set at 0 degrees. The results are shown below:

BIAS CALCULATED

	XO	YO	ALROT
REAL	0	-100.00000	0
CALCULATED	1.47177	-67.59963	-23.99265
DIFFERENCE	-1.47177	-32.40037	23.99265
RADIAL ERROR	32.43378		

BIAS SET = 0 DEGREES

	XO	YO	ALROT
REAL	0	-100.00000	0
CALCULATED	-3.67670	-86.62461	0
DIFFERENCE	3.67670	-11.37539	0
RADIAL ERROR	11.95482		

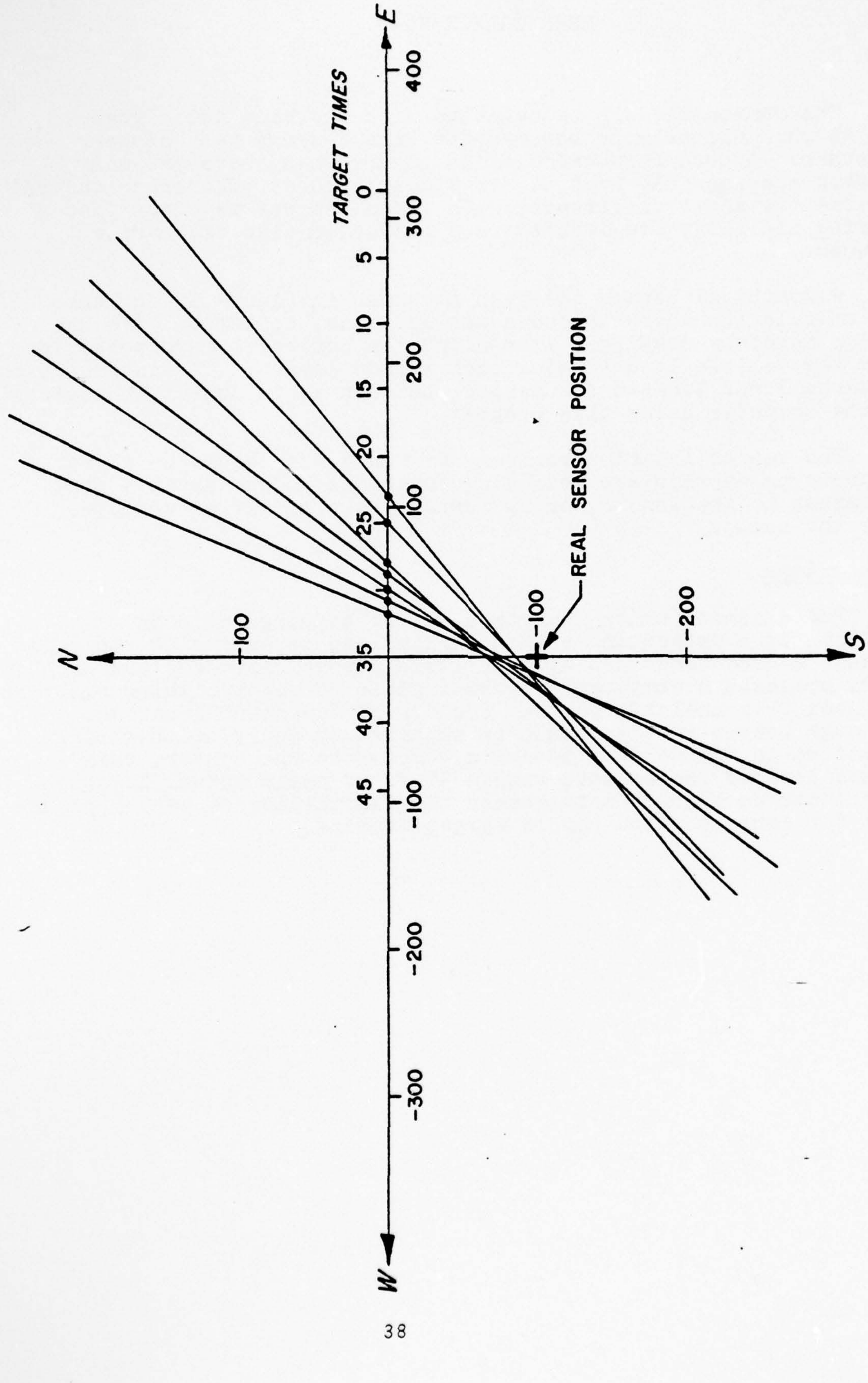
The reason the SPL calculation with the bias calculated was so poor was because the reports were few and very close together. A good bias calculation occurs when there are many reports and when the reports are widely spaced. The error occurs because the angle difference with close reports is often just a bearing bin shift and is not truly representative of bearing movement.

A graphical sensor location is shown in Figure 15 for the SPL calculation where the bias was set equal to zero. This was accomplished by drawing a line along the corrected report bearing from the vehicle location for each sensor report. The intersection of these lines locates the sensor position as is done arithmetically in the computer using this program.

The sensor location accuracy of these runs could be improved by applying appropriate weighting functions to the data, adding a compass to the sensor, or by running several target vehicles past the sensor.

Conclusions

For a sensor which reports a target bearing angle in addition to a detection, this algorithm can determine the location of that sensor after deployment. This report discusses the method used, presents a computer program capable of accomplishing the task, and does this analysis for two sensors of "unknown" location. Although better results could be obtained by applying weighting functions to the data or adding a compass to the sensor, this method located two sensors within 40 ft of their actual location. This location algorithm increases the flexibility of sensor placement for sensors which report target bearing.



SIMULATED SPL LINES (RUN #2); BIAS = 0 DEGREES

FIGURE 15

APPENDIX A

ERROR ANALYSIS

There are many factors which contribute to errors in accurately locating a sensor. These include:

1. Calculation of the rotational bias of the sensor, BIAS
2. Gaussian Noise, XK
3. Target course error, ΔALA
4. Target X position error, ΔX
5. Target Y position error, ΔY
6. Target Z position error, ΔZ
7. Target Velocity error, ΔV
8. Temperature error, Δ temp
9. The bearing resolution of the sensor, BINS

Errors due to these sources were computed for 58 simulated runs under four conditions. These conditions were:

1. Rotational bias calculated, one target vehicle
2. Rotational bias set, one target vehicle
3. Rotational bias calculated, two target vehicles
4. Rotational bias set, two target vehicles

The results of these runs are shown in Table 1. Unless specified the input parameters were:

BIAS = 0 degrees	V = 0 meters/sec
ΔXK = 0	temp = 0 degrees
ΔALA = 0 degrees	number of Bins = 100,000 (runs 1-47)
ΔX = 0 meters	
ΔY = 0 meters	number of Bins = 256 (runs 53-58)
Δ_Z = 0 meters	

These sensor location errors were calculated for sensor positions 100, 500, and 1000 meters from the target track. The vehicle was traveling at 50 m/s at an altitude of 200 m. The range of the target track was 3000 meters. In Table 1, DR_{100}, DR_{500}, and DR_{1000} refer to the distance of the sensor from the test track. All sensor location errors are in meters displayed from their actual location.

Bias Errors

In Table 1 the bias errors only affected the cases where the bias was set. In those cases, the bias was set equal to that error amount and the sensor position error was calculated. In the cases where the bias was calculated, it was calculated correctly as all other parameters were "error free." Using this correctly calculated bias the sensor position was accurate. Figure 16 shows the effect of bias errors on the SPL algorithm. The results are about the same for one or two targets, but do depend on the distance of the sensor from the target track.

Gaussian Noise

The signal received by the sensor from some target source contains noise. This noise affects the bearing angle reported by the sensor.

All noise is assumed to be Gaussian added to the real report bearing. This noise consists of an average value (Mean) and a standard deviation (Sigma). The mean is just the bias. Sigma is a function of the signal to noise ratio. The higher the ratio the lower the error. The following relationship has been observed:

$$\text{Sigma} = \frac{K_1}{S/N} \tag{35}$$

S/N is inversely proportional to the radial distance from the sensor to the target. Equation 36 depicts this relationship. where S/N_{cpa} is the signal to noise ratio at the closest point of approach (cpa).

TABLE 1 ERROR ANALYSIS OF SENSOR POSITION LOCATER

RUN NUMBER	ERROR TYPE	ERROR AMOUNT	ONE TARGET						TWO TARGETS					
			WITH CALCULATED BIAS			WITH BIAS SET			WITH CALCULATED BIAS			WITH BIAS SET		
			DR_{100}	DR_{500}	DR_{1000}	DR_{100}	DR_{500}	DR_{1000}	DR_{100}	DR_{500}	DR_{1000}	DR_{100}	DR_{500}	DR_{1000}
1	NONE	–	0	0	0	0	0	0	0	0	0	0	0	0
2	BIAS	20°	–	–	–	96	385	517	–	–	–	282	347	515
3	BIAS	10°	–	–	–	79	145	229	–	–	–	68	141	258
4	BIAS	5°	–	–	–	21	63	108	–	–	–	23	64	129
5	BIAS	1°	–	–	–	3	12	21	–	–	–	2.6	12	26
6	BIAS	1°	–	–	–	3	12	21	–	–	–	2.5	12	26
7	BIAS	5°	–	–	–	26	65	107	–	–	–	17	62	126
8	BIAS	-10°	–	–	–	82	149	225	–	–	–	50	128	241
9	BIAS	20°	–	–	–	299	362	519	–	–	–	463	342	487
10	XK	0.0001	0.2	0.8	2.4	0.1	0.5	1.5	0.2	0.7	0.3	0.1	0.3	1.1
11	XK	0.0010	12.1	9.1	28.9	11.6	6.5	16.8	7.6	9.3	35	4.5	9.0	16.4
12	XK	0.0050	416	216	509	265	150	363	127	32	203	337	33	85
13	XK	0.0100	6992	2074	901	120	1904	4023	1395	1244	289	476	2154	876
14	ΔALA	20°	869	885	935	960	546	1263	901	1038	1236	2961	1301	1565
15	ΔALA	10°	436	444	469	514	349	560	444	447	491	521	505	549
16	ΔALA	5°	218	222	235	235	199	255	209	177	188	212	175	154
17	ΔALA	1°	43	44	47	44	44	47	34	29	32	32	18	8.8
18	ΔALA	-1°	43	44	47	42	46	45	38	30	33	37	18	9.3
19	ΔALA	-5°	218	222	235	195	248	205	210	178	189	228	181	159
20	ΔALA	-10°	436	444	469	355	538	358	403	435	445	503	636	489
21	ΔALA	-20°	869	885	935	699	1190	546	884	1020	1040	504	1171	1332
22	ΔX	10 M	10	10	10	10	10	10	10	10	10	10	10	10
23	ΔX	5 M	5	5	5	5	5	5	5	5	5	5	5	5
24	ΔX	5 M	5	5	5	5	5	5	5	5	5	5	5	5
25	ΔX	-10 M	10	10	10	10	10	10	10	10	10	10	10	10
26	ΔY	10 M	10	10	10	10	10	10	10	10	10	10	10	10
27	ΔY	5 M	5	5	5	5	5	5	5	5	5	5	5	5
28	ΔY	-5 M	5	5	5	5	5	5	5	5	5	5	5	5
29	ΔY	-10 M	10	10	10	10	10	10	10	10	10	10	10	10
30	ΔZ	100 M	13.4	6.5	4.0	13.4	6.0	3.4	15.0	6.1	3.9	14.9	5.9	3.7
31	ΔZ	50 M	6.6	3.0	1.8	6.6	2.8	1.5	6.6	2.8	1.8	6.6	2.7	1.7
32	ΔZ	10 M	1.3	0.5	0.3	1.3	0.5	0.3	1.2	0.5	0.3	1.2	0.5	0.3
33	ΔZ	-10 M	1.3	0.5	0.3	1.3	0.5	0.3	1.2	0.5	0.3	1.2	0.5	0.3
34	ΔZ	-50 M	6.2	2.4	1.4	6.1	2.2	1.2	5.3	2.2	1.4	5.3	2.2	1.3
35	ΔZ	-100 M	11.6	4.1	2.4	11.5	3.8	2.1	9.6	3.7	2.4	9.5	3.7	2.2
36	ΔV	20 M/S	995	987	1027	994	975	995	1035	1186	1410	1034	1173	1378
37	ΔV	10 M/S	498	495	517	498	490	503	516	602	741	515	597	733
38	ΔV	5 M/S	249	248	259	249	246	252	252	307	390	252	305	389
39	ΔV	-5 M/S	249	249	261	249	248	256	260	301	385	290	301	385
40	ΔV	-10 M/S	499	500	523	499	497	514	516	856	749	516	612	751
41	ΔV	-20 M/S	999	1005	1054	999	1000	1040	1038	1210	1458	1039	1205	2635
42	ΔTEMP	20°C	1.2	2.6	4.0	1.3	2.3	6.0	1.1	3.0	6.1	1.1	3.2	6.4
43	ΔTEMP	10°C	0.6	1.3	2.0	0.7	1.7	3.1	0.6	1.5	3.1	0.6	1.6	3.3
44	ΔTEMP	- 5°C	0.3	0.7	1.0	0.3	0.9	1.5	0.3	0.8	1.6	0.3	0.8	1.7
45	ΔTEMP	5°C	0.3	0.7	1.0	0.3	0.9	1.6	0.3	0.8	1.6	0.3	0.8	1.7
46	ΔTEMP	-10°C	0.6	1.4	2.1	0.7	1.8	3.2	0.6	1.6	3.2	0.6	1.7	3.4
47	ΔTEMP	-20°C	1.3	2.8	4.3	1.4	3.6	6.5	1.2	3.2	6.5	1.2	3.4	6.9
48	# BINS	1024	0.2	0.2	1.3	0.1	0.2	1.3	0.1	0.1	0.3	0.0	0.2	0.2
49	# BINS	512	0.6	1.9	2.6	0.4	1.8	2.0	0.3	1.0	0.5	0.3	0.6	0.3
50	# BINS	256	0.6	3.7	2.8	0.4	0.1	2.5	0.6	2.3	2.3	0.2	0.0	0.5
51	# BINS	128	0.6	5.7	18.4	0.1	5.0	11.6	0.6	3.2	10.3	0.1	1.2	2.1
52	# BINS	64	5.4	23.4	12.9	3.1	22.7	26.0	2.6	6.3	24.3	1.8	5.3	23.1
53	XK	0.0001	0.2	6.0	9.4	0.3	2.5	5.2	0.3	1.3	4.6	0.2	1.8	0.9
54	XK	0.0010	7.5	9.3	32	6.4	5.7	32	4.4	6.4	16	3.0	5.9	10.6
55	XK	0.0050	623	275	690	146	228	636	300	148	123	413	116	114
56	XK	0.0100	1670	505	5284	5687	689	2266	4261	2763	203	710	352	101
57	BIAS	5°	1.0	5.2	4.0	239	63.7	107.5	0.4	2.1	1.9	22.5	63.4	128
58	BIAS	1°	0.4	10.2	5.0	37	12.7	21.2	0.6	2.4	4.6	2.7	12.3	25.7

AFFECTS OF BIAS ON SPL ERRORS

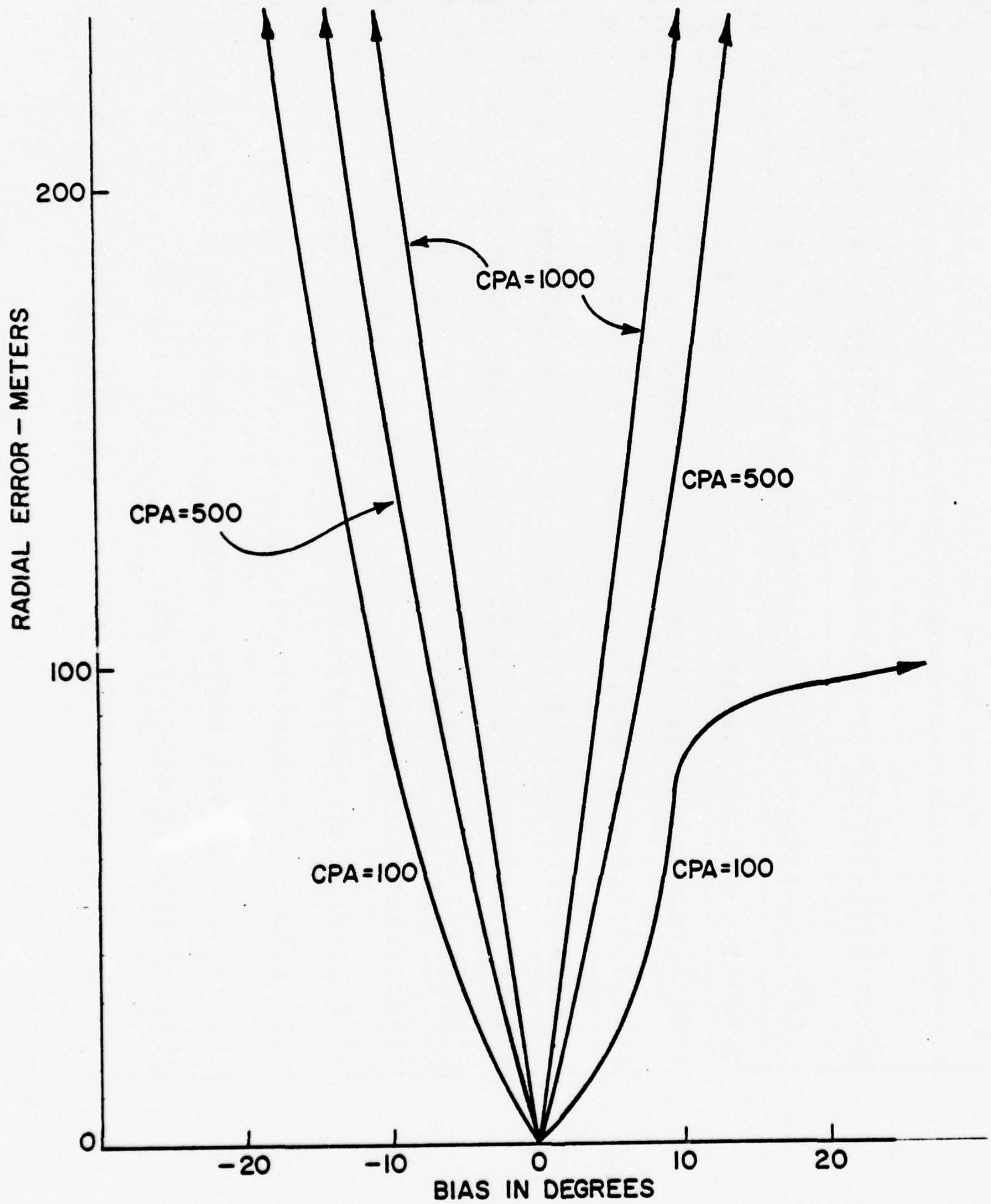


FIGURE 16

$$S/N = f(D) = \frac{K_2 + S/N_{cpa}}{\sqrt{D + 1}} \tag{36}$$

Combining equations 35 and 36 gives:

$$\text{Sigma} = K \sqrt{D + 1} \tag{37}$$

For the error analysis values of .0001, .001, .005, and .01 were used for K. Figure 17 plots the radial error (meters) of the sensor as a function of K. From Figure 17 it is noted that repeating the calculations for a second target greatly reduces the error from this source.

Target Course Error

This error comes about when the test vehicle is traveling in a direction slightly different than it is thought to be traveling. Figure 18 plots these errors as a function of course error (in degrees).

ΔX, ΔY Errors

This type of error occurs when the target vehicle is at a point different than it is thought to be. Equation 38 gives the radial error of the sensor as a function of the ΔX, ΔY displacement.

$$\text{radial error} = \sqrt{(\Delta X)^2 + (\Delta Y)^2} \tag{38}$$

The amount of this error is independent of whether the rotational bias is calculated or set equal to some value in the SPL algorithm, and it is independent of the number of test vehicles provided the ΔX, ΔY displacement of each vehicle is the same.

ΔZ Errors

This error results from inaccurate estimates of the differences in altitude between the target track plane and the sensor plane. It is independent of the number of targets used to sight in the

AFFECTS OF K (GAUSSIAN NOISE) ON SPL ERRORS

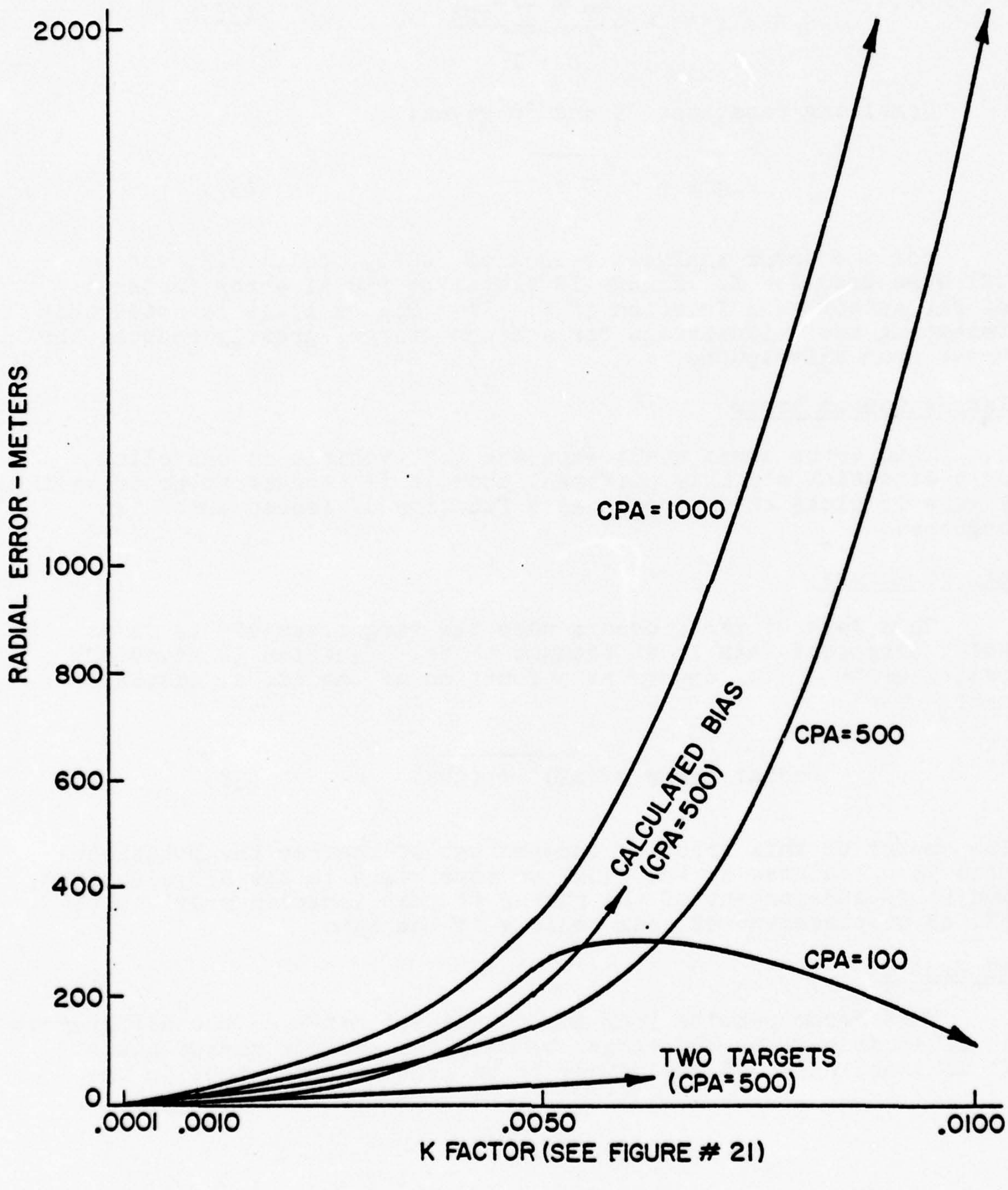


FIGURE 17

AFFECTS OF Δ COURSE ON SPL ERRORS

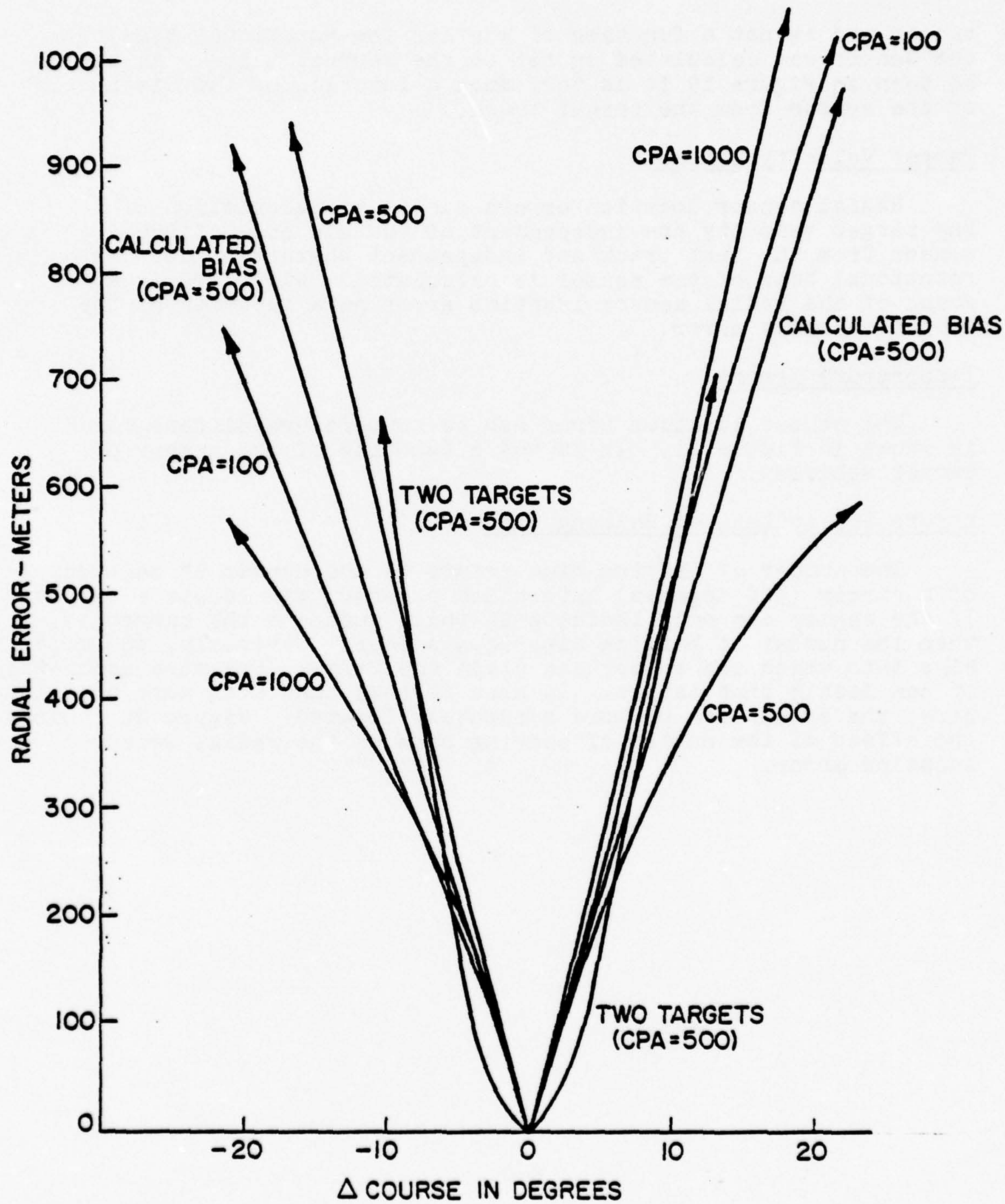


FIGURE 18

sensor and is not a function of whether the rotational bias of the sensor was calculated or set to the correct value. As can be seen in Figure 19 it is very much a function of the distance of the sensor from the target track.

Target Velocity Errors

Radial sensor location errors due to miscalculation of the target velocity are independent of the distance of the sensor from the test track and independent whether or not the rotational bias of the sensor is calculated. Figure 20 is a graph of the radial sensor location error as a function of the target velocity error.

Temperature Errors

The sensor location error due to temperature differences is shown in Figure 21. It is not a function of the number of target vehicles.

Errors Due to Lack of Bearing Bins

The number of bearing bins refers to the number of sections of a circle (360 degrees) into which a sensor can locate a target. If the sensor can only indicate in which quadrant the target is, then the number of bearing bins equals four. Obviously, the more bins into which the sensor can place the target, the more accurately it can locate that target. It also follows that with more bearing bins, the sensor can be more accurately located. Figure 22 depicts the affect of the number of bearing bins on the radial sensor location error.

AFFECTS OF ΔZ ON SPL ERRORS

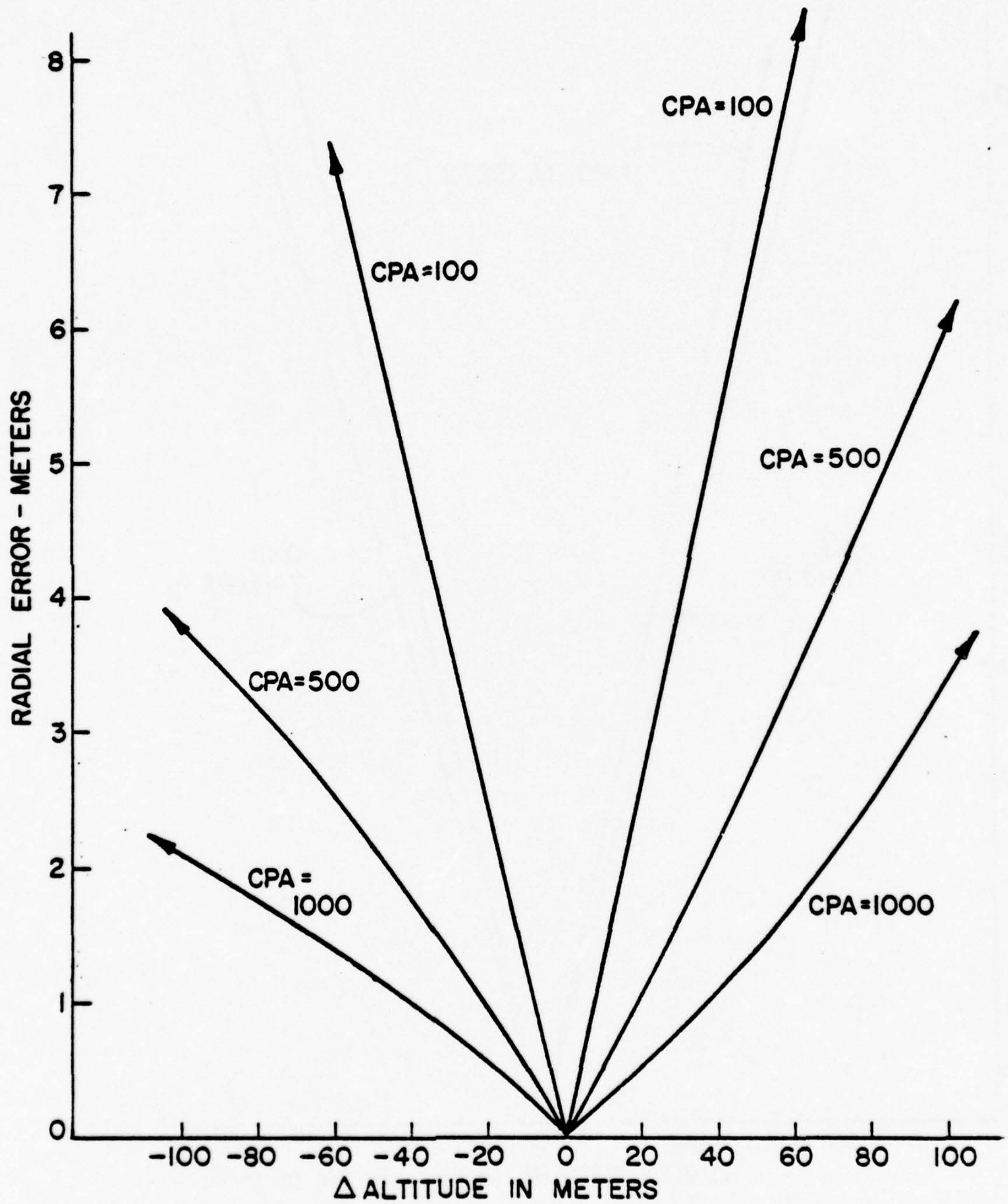


FIGURE 19

AFFECTS OF Δ VELOCITY ON SPL ERRORS

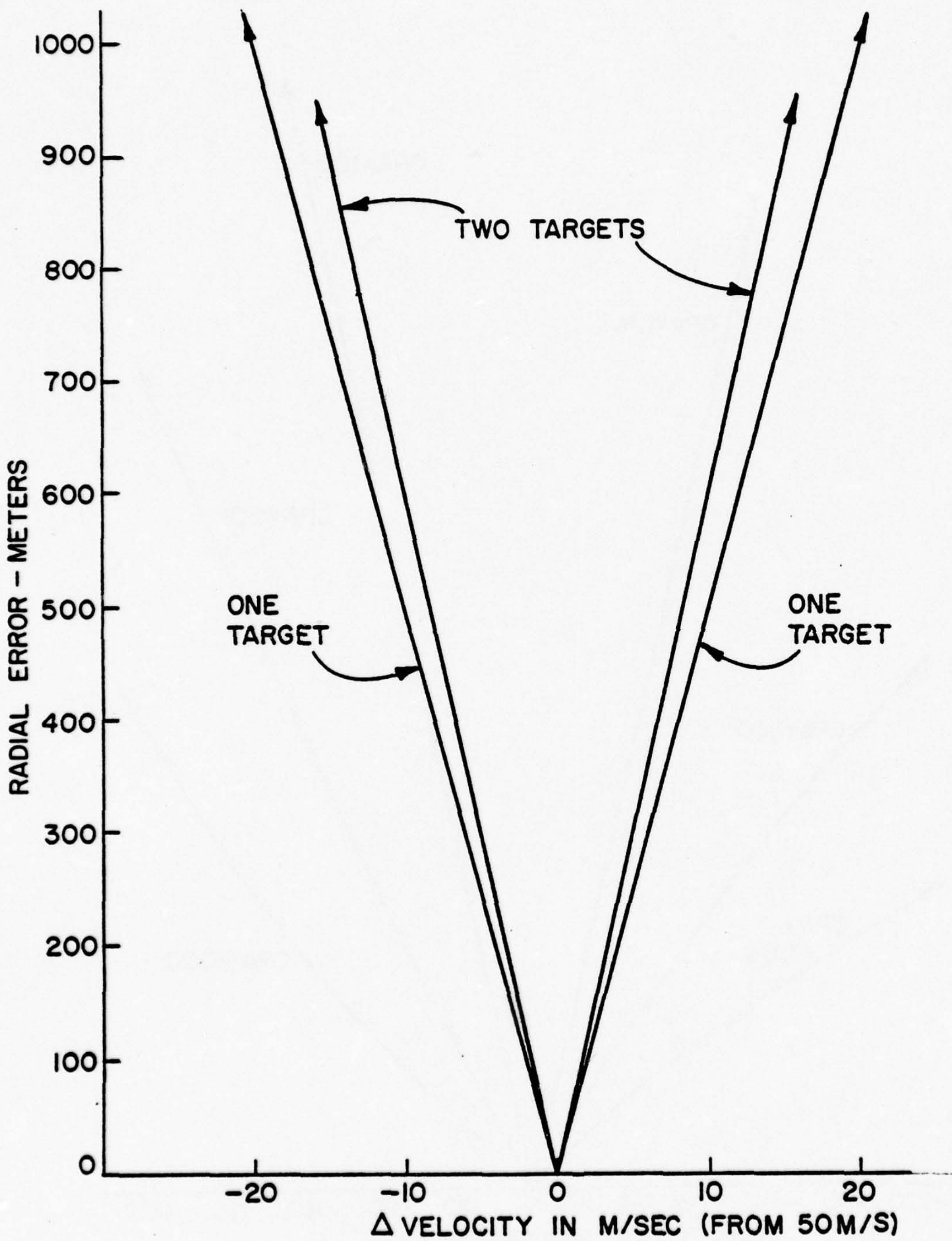


FIGURE 20

AFFECTS OF Δ TEMPERATURE ON SPL ERRORS

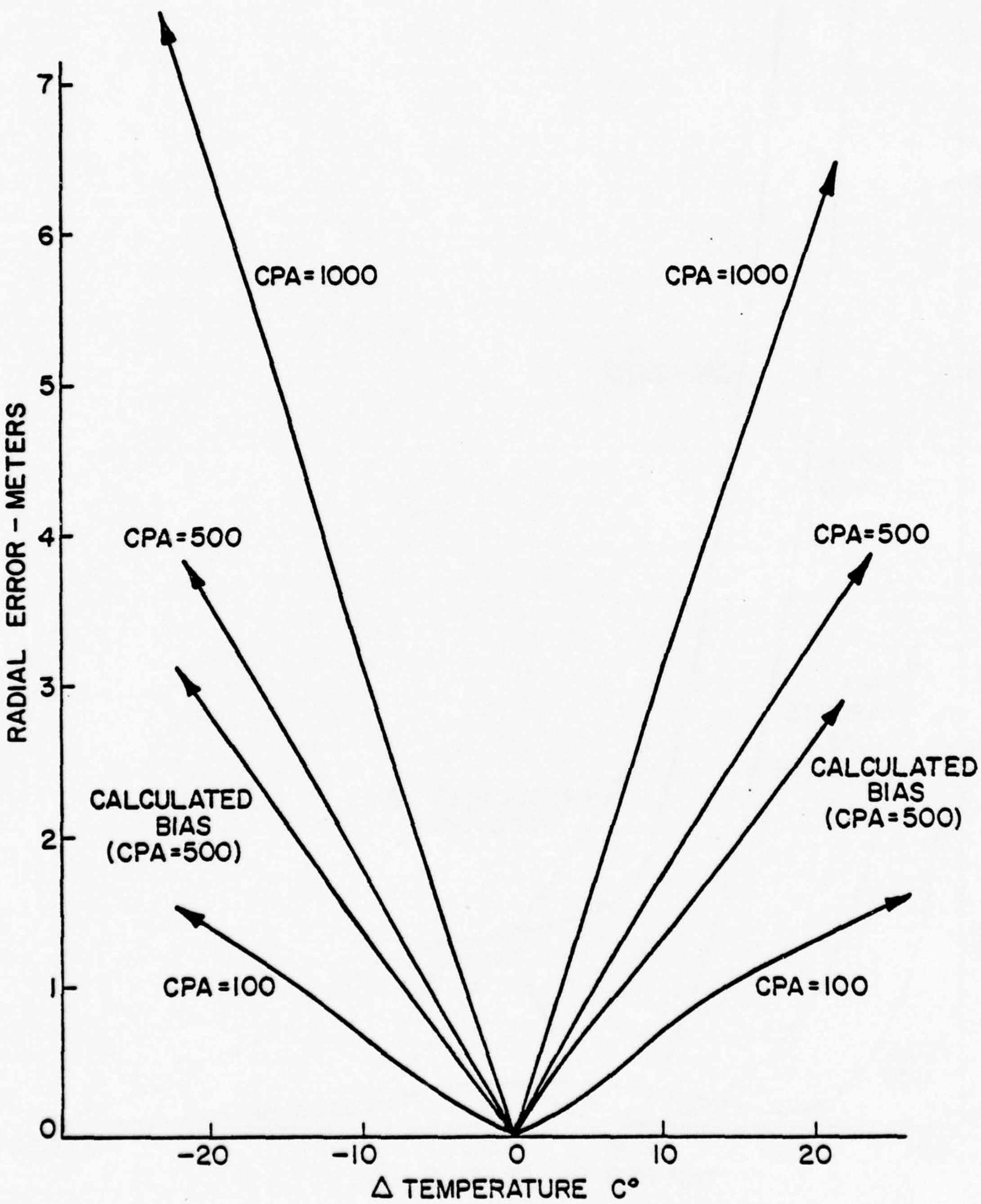


FIGURE 21

AFFECTS OF NUMBER OF BEARING BINS ON SPL ERRORS

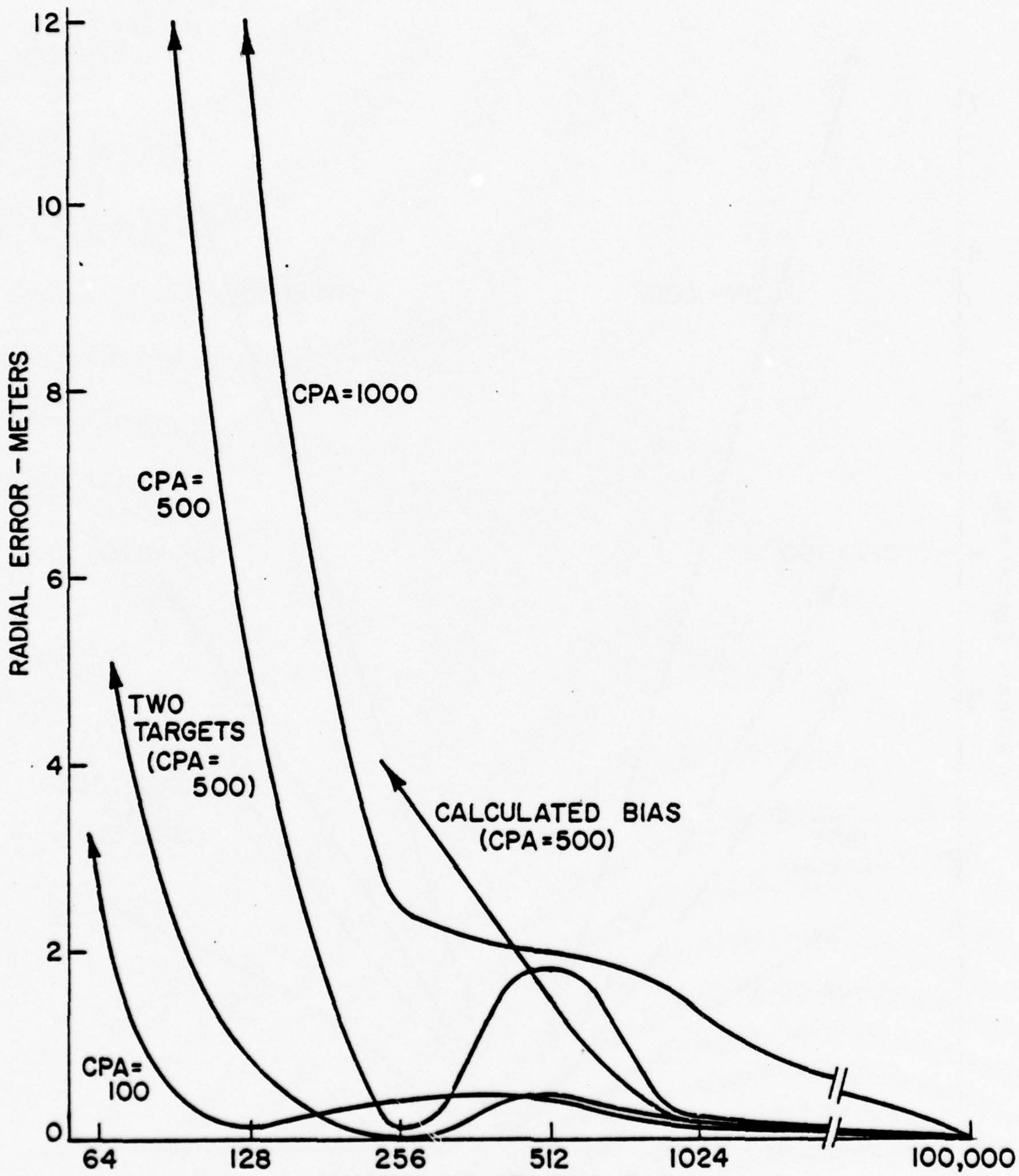


FIGURE 22

APPENDIX B

FORTRAN PROGRAMS AND FLOW CHARTS

Since there are many calculations involved in locating a sensor position, it is best done using a computer. Appendix B is a listing of the flow charts and the computer program used to accomplish this. The computer program is called Simulate, and it calls nine subroutines called Input, Senchk, Output, SPL, Enter, Shift, TXY, Normal and Uniform.

Program Simulate is the program which locates the sensor position. It accomplishes this by calling four subroutines; INPUT, SENCHK, SPL, and OUTPUT.

Subroutine INPUT loads the initial parameters into the program.

Subroutine SENCHK picks which sensor reports should be used in the calculation. For those reports it provides the time of report, report bearing, and a weighting function to the main program.

Subroutine SPL calculates the sensor location and the rotational bias from the data provided to it from the main program.

Subroutine OUTPUT prints out the results of the calculations.

There are five other subroutines which are used in this program. Subroutines Normal and Uniform together provide a random number uniformly distributed between 0 and 1 to Subroutine SENCHK. Subroutines Enter, Shift, and TXY simply perform minor arithmetic calculations needed in the SPL Subroutine.

The flow charts, Figures 23-30, and computer printout for these programs, Figure 31, follow.

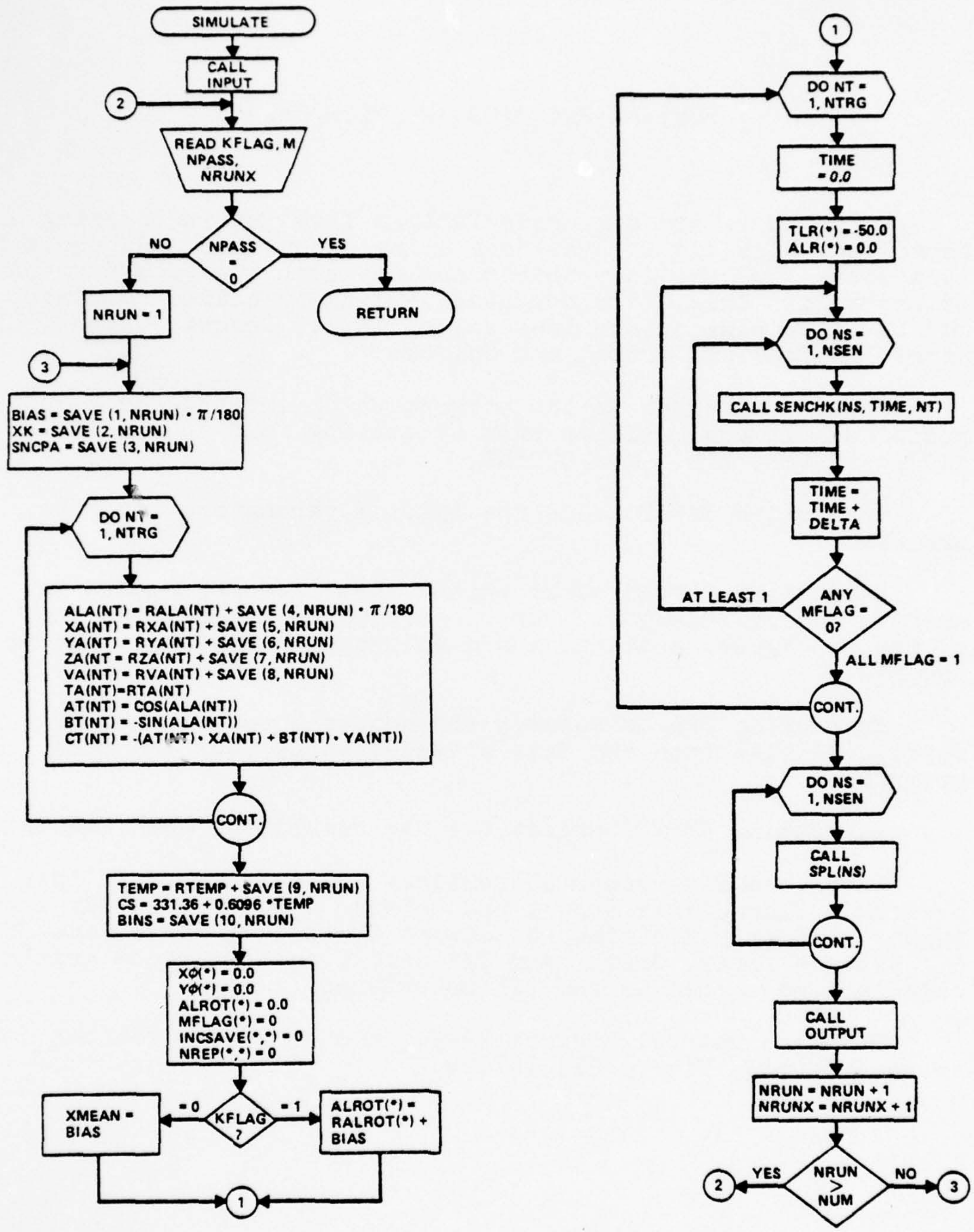


FIG. 23 FLOWCHART OF SIMULATE

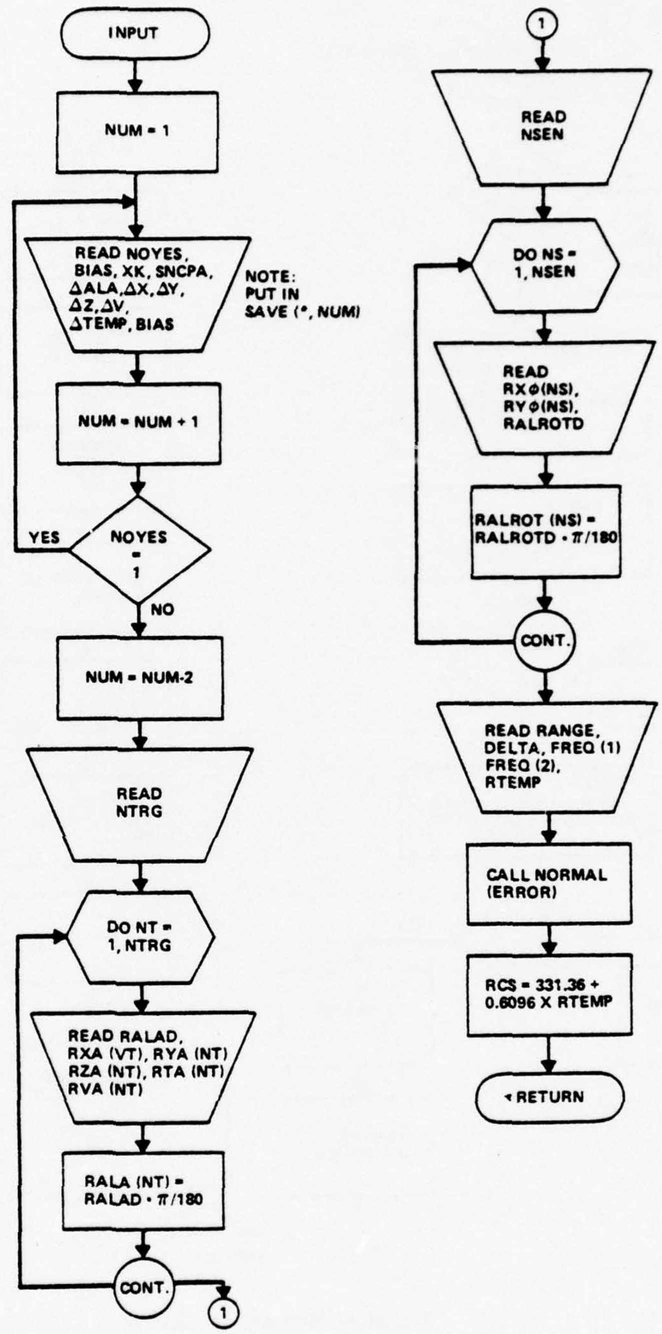


FIG. 24 FLOWCHART OF INPUT

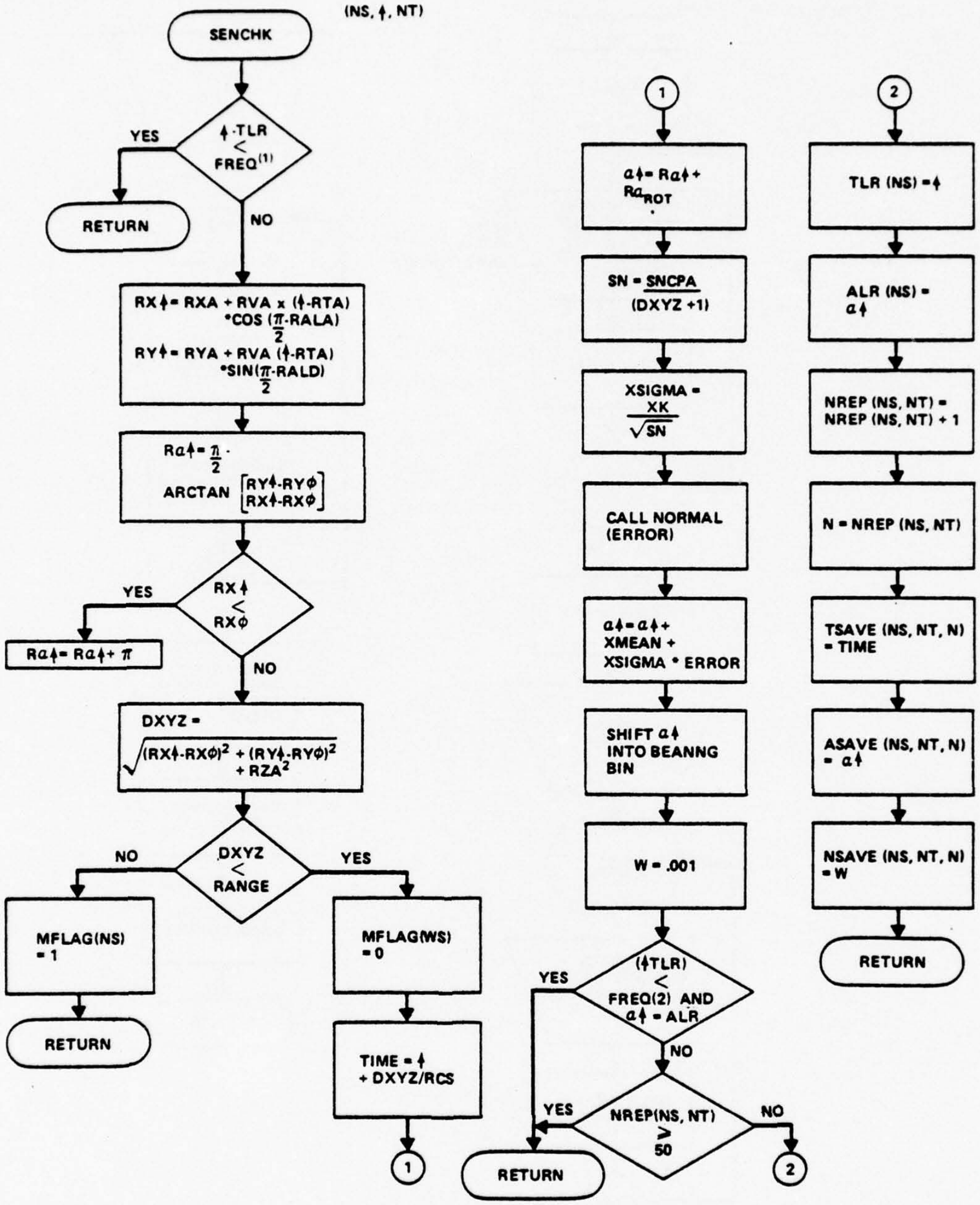


FIG. 25 FLOWCHART OF SENCHK

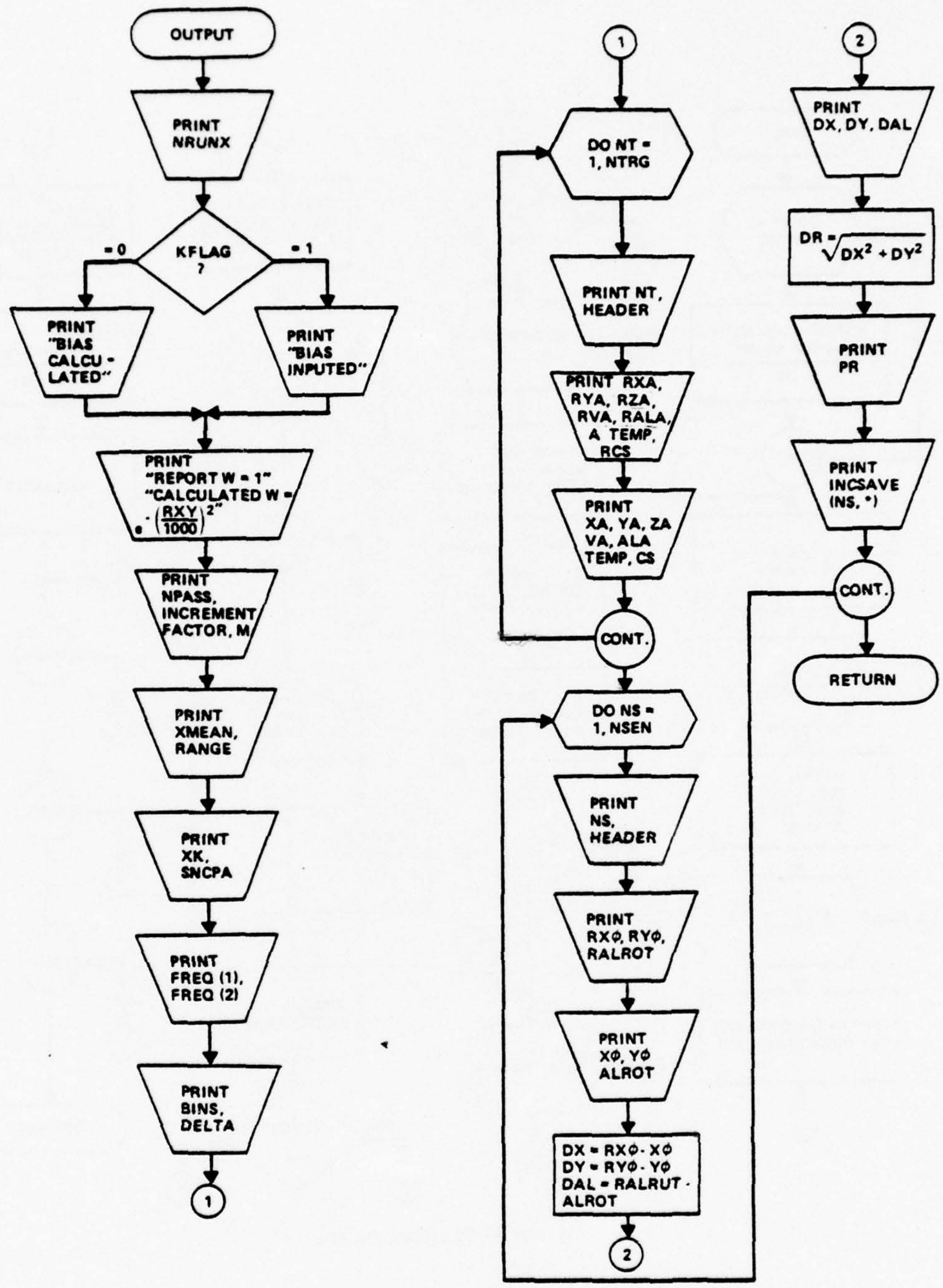


FIG. 26 FLOWCHART OF OUTPUT

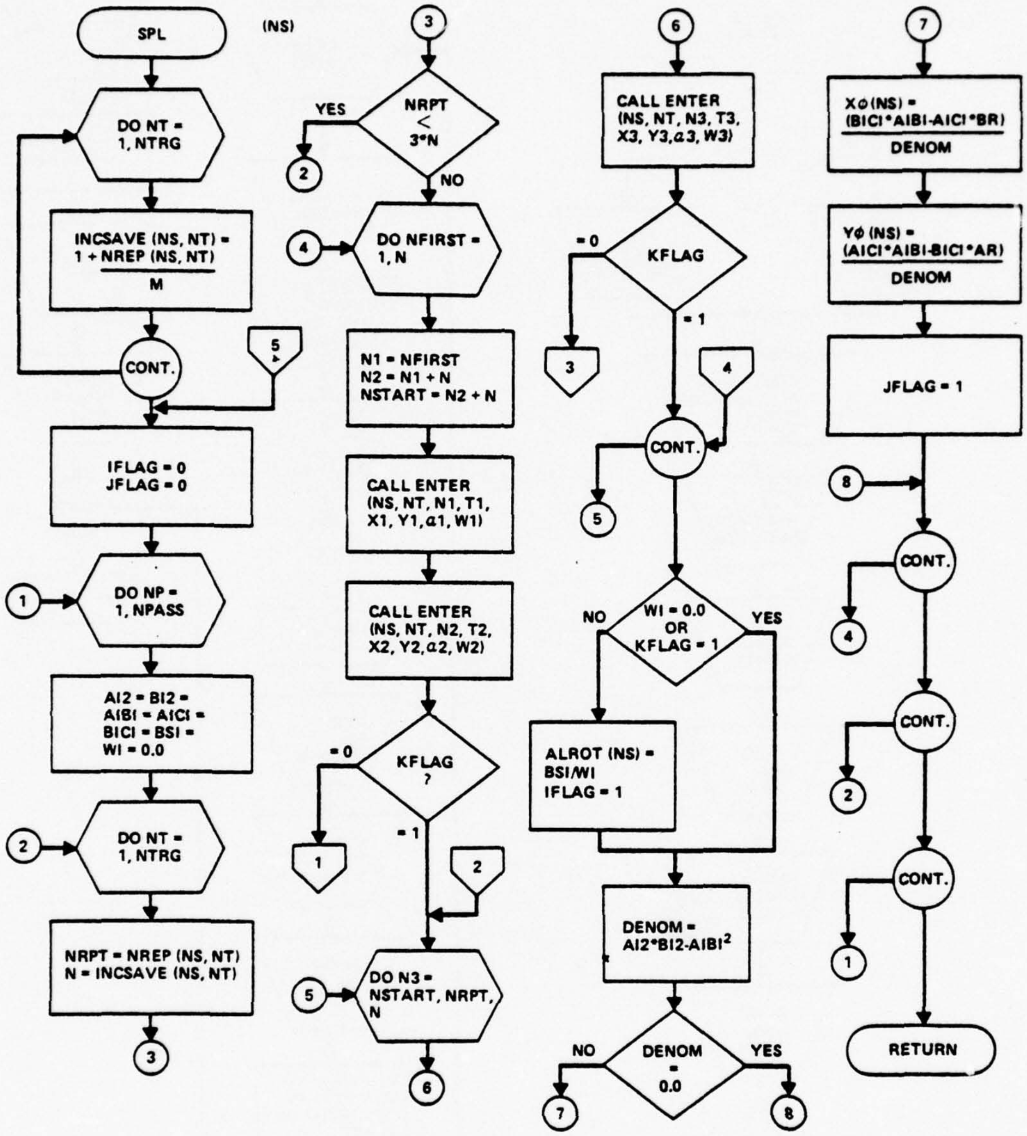


FIG. 27a FLOWCHART OF SPL

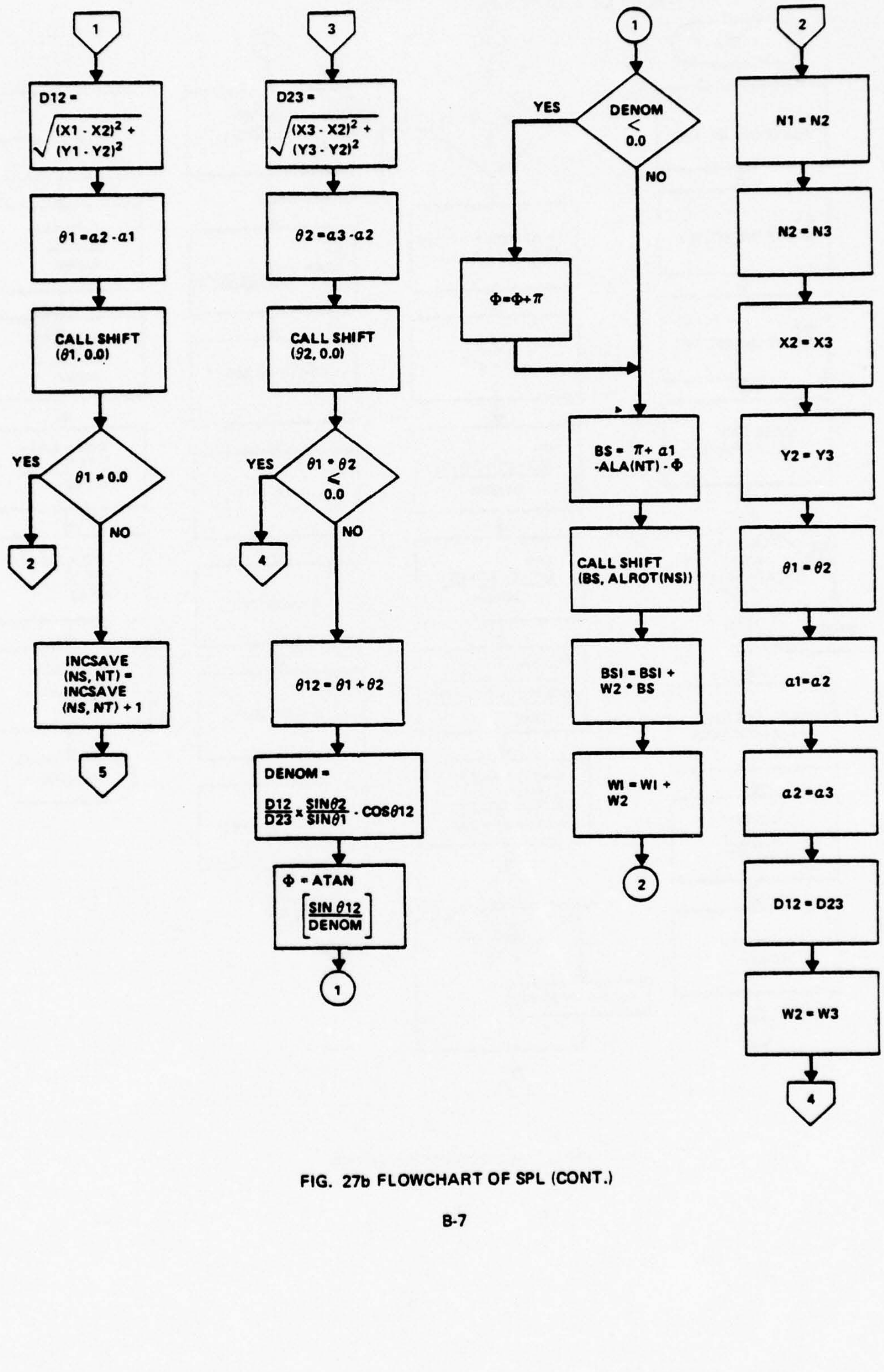


FIG. 27b FLOWCHART OF SPL (CONT.)

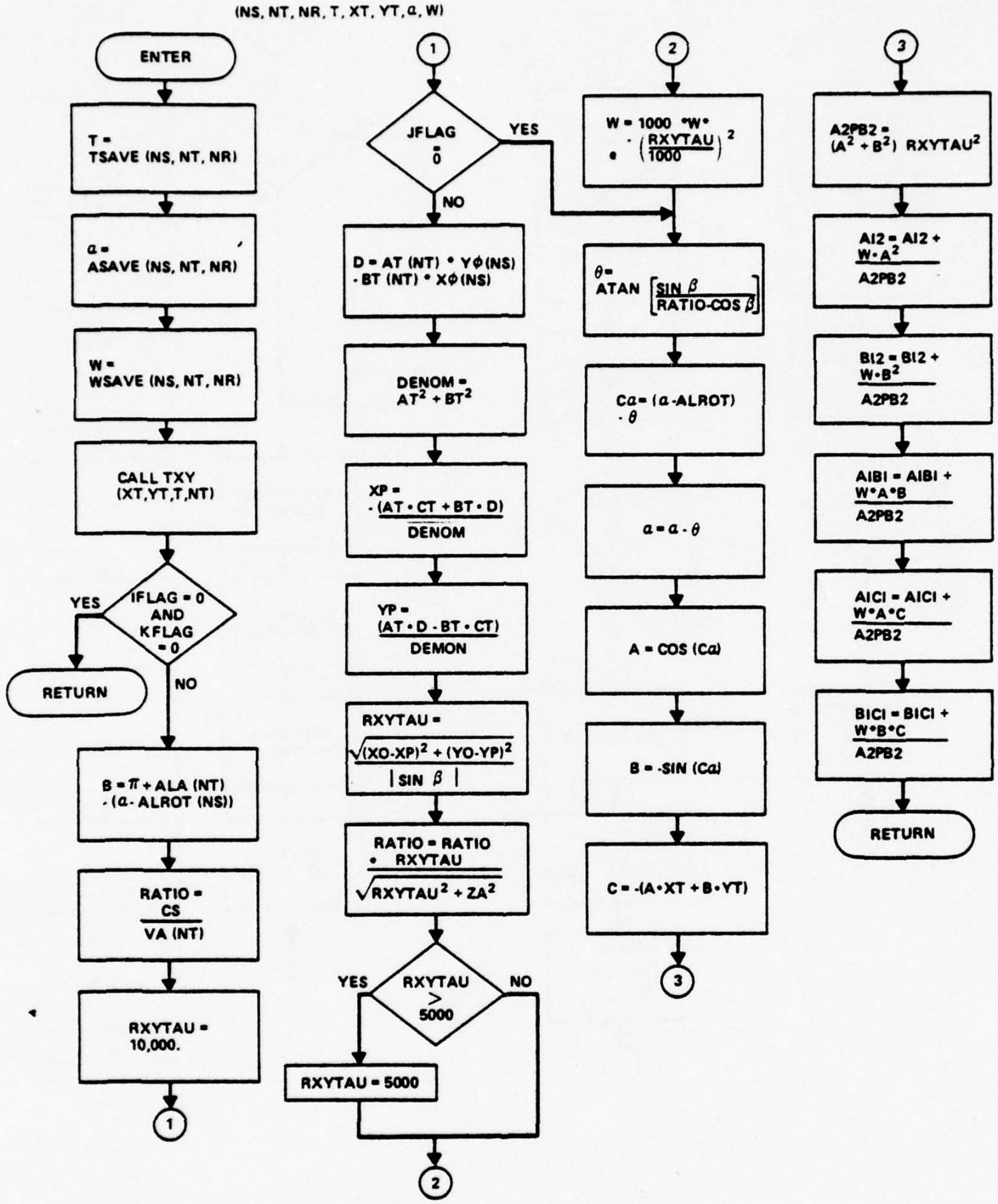


FIG. 28 FLOWCHART OF ENTER

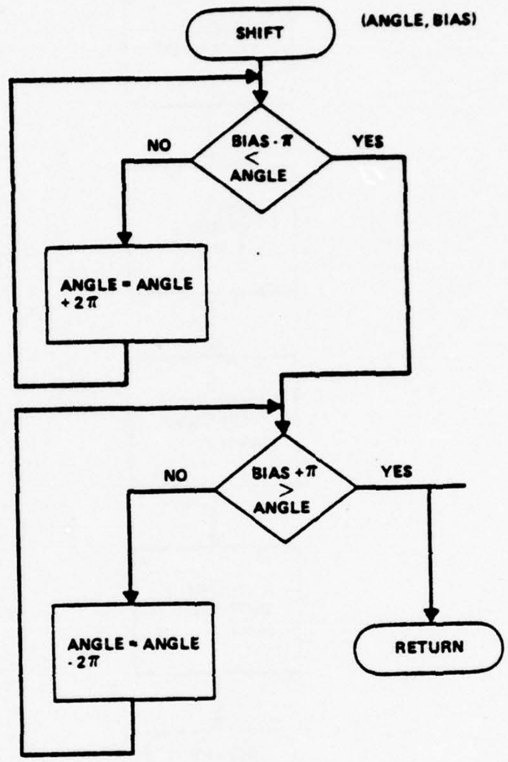


FIG. 29 FLOWCHART OF SHIFT

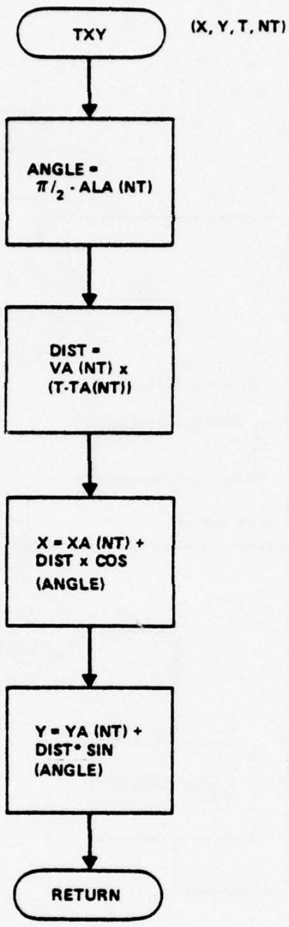


FIG. 30 FLOWCHART OF TXY

SCL FORTRAN (1.0)

```
00000          PROGRAM SIMULATE
      C
      C
      C   ****************************************************************
      C   *                                                              *
      C   *   JONATHAN VALVANO                                  03/18/75 *
      C   *                                                              *
      C   *   THESE PROGRAMS SIMULATE A SENSOR FIELD FOR THE             *
      C   *   DEVELOPMENT OF A SENSOR POSITION LOCATOR (SPL).            *
      C   *   ACOUSTIC SENSORS ARE DEPLOYED IN THE FIELD WITHOUT         *
      C   *   THE KNOWLEDGE OF THEIR EXACT LOCATION.  THIS CAN BE DONE   *
      C   *   BY AIR DROP OR GUN DELIVERY.  THE PURPOSE OF THESE         *
      C   *   ROUTINES IS TO LOCATE THE SENSORS ONCE THEY ARE IN THE     *
      C   *   FIELD.  THE FOLLOWING METHOD IS USED....                   *
      C   *        1. A TARGET, WHOSE POSITION AS A FUNCTION OF TIME     *
      C   *           IS KNOWN, IS RUN OVER THE SENSOR FIELD.            *
      C   *        2. THE RECIEVING UNIT LISTENS AND RECORDS THE SEQUENCE*
      C   *           OF REPORTS BY THE SENSOR OF THE TARGET.            *
      C   *        3. THE ARRAYS OF REPORTS PLUS THE TARGET LOCATIONS    *
      C   *           ARE FED AS INPUTS TO THE SPL ALGORITHM.            *
      C   *        4. SPL CALCULATES THE SENSOR LOCATION (AND BIAS ANGLE)*
      C   *                                                              *
      C   *   THE FOLLOWING OPTIONS ARE AVAILABLE TO SPL...              *
      C   *        KFLAG=0 IF THE BIAS IS TO BE CALCULATED.              *
      C   *        KFLAG=1 IF THE BIAS IS REPORTED ( INPUTED TO SPL.)    *
      C   *        M IS THE INCREMENT FACTOR (SEE SPL)                   *
      C   *        NPASS IS THE NUMBER OF PASSES SPL MAKES OVER REPORTS  *
      C   *                                                              *
      C   *   THE FOLLOWING OPTIONS ARE AVAILABLE TO THE SIMULATION...   *
      C   *        NSEN      THE NUMBER OF SENSORS                       *
      C   *        NTRG      THE NUMBER OF TARGETS                       *
      C   *        RANGE     THE RANGE OF THE SENSORS                    *
      C   *        BINS      THE NUMBER OF BEARING BINS OF THE SENSOR    *
      C   *        FREQ(1)   THE CYCLE TIME WHEN THE BEARING CHANGES     *
      C   *        FREQ(2)   THE CYCLE TIME WHEN THE BEARING IS THE SAME *
      C   *        DELTA     THE TIME INCREMENT IN THE SIMULATION        *
      C   *        XMEAN,XK,SNCPA  ARE FOR GAUSSIAN ERROR                *
      C   *                  MEAN=XMEAN                                  *
      C   *                  SIGMA=XK/SQRT(SNCPA/(DXYZ+1))               *
      C   *                                                              *
      C   ****************************************************************
      C
00001          COMMON /TRGT// ALA(3),XA(3),YA(3),ZA(3),
00001        1 TA(3),VA(3),AT(3),BT(3),CT(3),TEMP,CS,NTRG
00002          COMMON /RTRGT// RALA(3),RXA(3),RYA(3),RZA(3),
00002        1 RTA(3),RVA(3),RTEMP,RCS
00003          COMMON /SEN// NSEN,X0(3),Y0(3),ALROT(3),IFLAG,JFLAG
00004          COMMON /RSEN// RX0(3),RY0(3),RALROT(3)
00005          COMMON /REP// TSAVE(3,3,50),ASAVE(3,3,50),WSAVE(3,3,50),
00005        1 NREP(3,3),INCSAVE(3,3)
00006          COMMON /STATE// TLR(3),ALR(3),MFLAG(3),FREQ(2),
00006        1 BINS,XMEAN,XK,SNCPA,RANGE,DELTA,NUM,NRUN,NRUNX,SAVE(10,100)
00007          COMMON /CONST// PI,PIO2,PI2
00008          COMMON /OPTIONS// KFLAG,M,NPASS
```

FIG. 31 COMPUTER PROGRAM

```
C
C     *****************************************************************
C     *                                                               *
C     *     FIRST CALL INPUT TO SET UP THE SIMULATION                 *
C     *                                                               *
C     *****************************************************************
C
            CALL INPUT
C
C     *****************************************************************
C     *                                                               *
C     *     THEN READ THE OPTIONS FOR THIS SET OF RUNS                *
C     *     THIS IS THE START OF A SET OF RUNS WITH SEPERATE OPTIONS. *
C     *                                                               *
C     *****************************************************************
C
  101       READ 103, KFLAG,M,NPASS,NRUNX
  103       FORMAT (4I10)
            IF (NPASS .EQ. 0) RETURN
            NRUN=1
C
C
C     *****************************************************************
C     *                                                               *
C     *     SAVE CONTAINS THE SIMULATION OPTIONS FOR EACH RUN OF SET  *
C     *                                                               *
C     *     ALL ANGLE INPUTS AND OUTPUTS ARE IN DEGREES AND           *
C     *     ALL INTERNAL ANGLES ARE IN RADIANS.                       *
C     *                                                               *
C     *     ALA  IS THE INPUTED TARGET COURSE.                        *
C     *     RALA IS THE REAL    TARGET COURSE.                        *
C     *     VA   IS THE INPUTED TARGET VELOCITY.                      *
C     *     RVA IS THE REAL     TARGET VELOCITY.                      *
C     *     AT TIME TA (SECONDS THE TARGET IS AT (XA,YA,ZA) INPUTED.  *
C     *     AT TIME RTA (SEC) THE TARGET IS AT (RXA,RYA,RZA)  REAL.   *
C     *                                                               *
C     *****************************************************************
C
C
C
  110       BIAS=SAVE(1,NRUN)*PI/180.0
            XK=SAVE(2,NRUN)
            SNCPA=SAVE(3,NRUN)
            DO 155 NT=1,NTRG
            ALA(NT)=RALA(NT)+SAVE(4,NRUN)*PI/180.0
            XA(NT)=RXA(NT)+SAVE(5,NRUN)
            YA(NT)=RYA(NT)+SAVE(6,NRUN)
            ZA(NT)=RZA(NT)+SAVE(7,NRUN)
            VA(NT)=RVA(NT)+SAVE(8,NRUN)
            TA(NT)=RTA(NT)
C
C
C
C
C
```

```
      C
      C     ***************************************************************
      C     *                                                             *
      C     *    AT,BT,CT FORM THE LINE AT*X+BT*Y+CT=0 OF THE TARGET TRACK. *
      C     *                                                             *
      C     *                                                             *
      C     ***************************************************************
      C
                AT(NT)=COS(ALA(NT))
                BT(NT)=-SIN(ALA(NT))
                CT(NT)=-(AT(NT)*XA(NT)+BT(NT)*YA(NT))
        155     CONTINUE
      C
      C
      C
      C
      C
      C
      C     ***************************************************************
      C     *                                                             *
      C     *    CS  IS THE INPUTED SPEED OF SOUND IN METERS/SECOND.      *
      C     *    RCS IS THE REAL    SPEED OF SOUND IN METERS/SECOND.      *
      C     *    TEMP  IS THE INPUTED TEMPERATURE IN CENTIGRADE.          *
      C     *    RTEMP IS THE REAL    TEMPERATURE IN CENTIGRADE.          *
      C     *                                                             *
      C     ***************************************************************
      C
                TEMP=RTEMP+SAVE(9,NRUN)
                CS=331.36+0.6096*TEMP
                BINS=SAVE(10,NRUN)
                DO 160 I=1,3
      C
      C     ***************************************************************
      C     *                                                             *
      C     *    (X0,Y0) IS THE CALCULATED SENSOR POSITION.               *
      C     *    (RX0,RY0) IS THE REAL SENSOR POSITION.                   *
      C     *    ALROT IS EITHER THE CALCULATED OR INPUTED SENSOR         *
      C     *         ANGLE ROTATION BIAS, DEPENDING ON OPTION- KFLAG.    *
      C     *    RALROT IS THE REAL SENSOR ANGLE ROTATION BIAS.           *
      C     *                                                             *
      C     *    MFLAG=0 WHEN THE TARGET IS WITHIN RANGE OF THAT SENSOR.  *
      C     *    MFLAG=1 WHEN THE TARGET IS OUTSIDE THE RANGE OF THAT SENSOR*
      C     *                                                             *
      C     ***************************************************************
      C
                X0(I)=0.0
                Y0(I)=0.0
                ALROT(I)=0.0
                MFLAG(I)=0
                IF (KFLAG .EQ. 0) XMEAN=BIAS
                IF (KFLAG .EQ. 1) ALROT(I)=RALROT(I)+BIAS
                DO 160 J=1,3
                INCSAVE(I,J)=0
        160     NREP(I,J)=0
```

```
              DO 125 NT=1,NTRG
              TIME=0.0
              DO 111 I=1,3
C
C    ****************************************************************
C    *                                                              *
C    *        TLR IS THE TIME OF THE LAST REPORT.                   *
C    *        ALR IS THE ANGLE OF THE LAST REPORT.                  *
C    *                                                              *
C    ****************************************************************
C
              TLR(I)=-50.0
              ALR(I)=0.0
  111         CONTINUE
  115         DO 120 NS=1,NSEN
C
C    ****************************************************************
C    *                                                              *
C    *        SENCHK WILL CHECK TO SEE IF THE SENSOR SHOULD REPORT. *
C    *        IF SO IT DETERMINES THE TIME OF THE REPORT AND PUTS IT *
C    *        IN TSAVE. IT DETERMINES THE BEARING AND PUTS IT IN ASAVE. *
C    *        IF THE SENSOR REPORTS A WEIGHTING FACTOR IT IS  IN WSAVE. *
C    *                                                              *
C    ****************************************************************
C
  120         CALL SENCHK(NS,TIME,NT)
              TIME=TIME+DELTA
              DO 121 NS=1,NSEN
              IF (MFLAG(NS) .EQ. 0) GO TO 115
  121         CONTINUE
  125         CONTINUE
C
C    ****************************************************************
C    *                                                              *
C    *        NOW THE ARRAYS (TSAVE,ASAVE,WSAVE) ARE FULL.          *
C    *                                                              *
C    ****************************************************************
C
              DO 130 NS=1,NSEN
C
C    ****************************************************************
C    *                                                              *
C    *        CALL THE SENSOR POSITION LOCATOR (SPL).               *
C    *                                                              *
C    ****************************************************************
C
              CALL SPL(NS)
  130         CONTINUE
C
C
C
C
C
C
```

```
             C
             C    ****************************************************************
             C    *                                                              *
             C    *    CALL OUTPUT TO PRINT RESULTS.                             *
             C    *                                                              *
             C    ****************************************************************
             C
  00061                CALL OUTPUT
  00062                NRUN=NRUN+1
  00063                NRUNX=NRUNX+1
  00064                IF (NRUN .GT. NUM) GO TO 101
  00066                GO TO 110
  00067                END
```

NOL FORTRAN DIAGNOSTIC RESULTS - FOR   SIMULATE

NO ERRORS

DATA VARIABLES

ALA	00001	00019	00025	00026	
ALR	00006	00048			
ALROT	00003	00035	00040		
ASAVE	00005				
AT	00001	00025	00027		
BINS	00006	00031			
BT	00001	00026	00027		
CS	00001	00030			
CT	00001	00027			
DELTA	00006	00052			
FREQ	00006				
IFLAG	00003				
INCSAVE	00005	00042			
JFLAG	00003				
KFLAG	00008	00010	00037	00039	
M	00008	00010			
MFLAG	00006	00036	00054		
NPASS	00008	00010	00012		
NREP	00005	00043			
NRUN	00006	00014	00015	00016	00017
	00023	00029	00031	00062	00062
NRUNX	00006	00010	00063	00063	
NSEN	00003	00050	00053	00058	
NTRG	00001	00018	00044		
NUM	00006	00064			
PI	00007	00015	00019		
PI2	00007				
PID2	00007				
RALA	00002	00019			
RALROT	00004	00040			
RANGE	00006				
RCS	00002				
RTA	00002	00024			
RTEMP	00002	00029			
RVA	00002	00023			
RX0	00004				
RXA	00002	00020			
RY0	00004				
RYA	00002	00021			
RZA	00002	00022			
SAVE	00006	00015	00016	00017	00019
	00029	00031			
SNCPA	00006	00017			
TA	00001	00024			
TEMP	00001	00029	00030		
TLR	00006	00047			
TSAVE	00005				
VA	00001	00023			
WSAVE	00005				
X0	00003	00033			
XA	00001	00020	00027		
XK	00006	00016			

XMEAN	00006	00038			
Y0	00003	00034			
YA	00001	00021	00027		
ZA	00001	00022			

COMMON VARIABLES

NONE

PROGRAM VARIABLES

BIAS	00015	00038	00040		
COS	00025				
I	00032	00033	00034	00035	00036
	00046	00047	00048		
INPUT	00009				
J	00041	00042	00043		
NS	00050	00051	00053	00054	00058
NT	00018	00019	00019	00020	00020
	00023	00023	00024	00024	00025
	00027	00027	00027	00027	00044
OUTPUT	00061				
SENCHK	00051				
SIN	00026				
SPL	00059				
TIME	00049	00051	00052	00052	

INPUT DECK/ L.R.X

NOL FORTRAN (1.0)

```
            SUBROUTINE INPUT
      C
      C     ***************************************************************
      C     *                                                             *
      C     *     JONATHAN VALVANO                             03/16/75  *
      C     *                                                             *
      C     *     THIS ROUTINE INPUTS INITIAL PARAMETERS.                 *
      C     *     ALL ANGLE INPUTS ARE IN DEGREES.                        *
      C     *                                                             *
      C     ***************************************************************
      C
            COMMON /TRGT// ALA(3),XA(3),YA(3),ZA(3),
           1 TA(3),VA(3),AT(3),BT(3),CT(3),TEMP,CS,NTRG
            COMMON /RTRGT// RALA(3),RXA(3),RYA(3),RZA(3),
           1 RTA(3),RVA(3),RTEMP,RCS
            COMMON /SEN// NSEN,X0(3),Y0(3),ALROT(3),IFLAG,JFLAG
            COMMON /RSEN// RX0(3),RY0(3),RALROT(3)
            COMMON /REP// TSAVE(3,3,50),ASAVE(3,3,50),WSAVE(3,3,50),
           1 NREP(3,3),INCSAVE(3,3)
            COMMON /STATE// TLR(3),ALR(3),MFLAG(3),FREQ(2),
           1 BINS,XMEAN,XK,SNCPA,RANGE,DELTA,NUM,NRUN,NRUNX,SAVE(10,100)
            COMMON /CONST// PI,PID2,PI2
            COMMON /OPTIONS// KFLAG,M,NPASS
            DATA /CONST/ (PI=3.1415926538)
            DATA /CONST/ (PID2=1.570796327)
            DATA /CONST/ (PI2=6.283185307)
            DATA /REP/ (NREP(1)=9(0))
            DATA /STATE/ (TLR(1)=3(-50.0))
            DATA /STATE/ (ALR(1)=3(0.0))
      C
      C
      C
      C
      C
      C     ***************************************************************
      C     *                                                             *
      C     *     READ SIMULATION OPTIONS.                                *
      C     *     NUM IS THE NUMBER OF RUNS IN A SET.                     *
      C     *                                                             *
      C     ***************************************************************
      C
            NUM=1
        279 READ 280, NOYES,(SAVE(I,NUM), I=1,10)
        280 FORMAT (I5,F5.0,F10.4,7F5.0,F10.0)
            NUM=NUM+1
            IF (NOYES .EQ. 1) GO TO 279
            NUM=NUM-2
      C
      C
      C
      C
      C
      C
      C
```

```
            READ 200, NTRG
  200       FORMAT (I5)
            DO 225 NT=1,NTRG
C
C     ****************************************************************
C     *                                                              *
C     *     READ REAL TARGET CHARACTERISTICS.                        *
C     *                                                              *
C     ****************************************************************
C
            READ 220, RALAD,RXA(NT),RYA(NT),RZA(NT),RTA(NT),RVA(NT)
  220       FORMAT (6F10.2)
            RALA(NT)=RALAD*PI/180.0
  225       CONTINUE
            READ 230, NSEN
  230       FORMAT (I5)
            DO 250  NS=1,NSEN
C
C     ****************************************************************
C     *                                                              *
C     *     READ REAL SENSOR CHARACTERISTICS.                        *
C     *                                                              *
C     ****************************************************************
C
            READ 240, RX0(NS),RY0(NS),RALROTD
  240       FORMAT (3F10.2)
            RALROT(NS)=RALROTD*PI/180.0
  250       CONTINUE
            READ 290, RANGE,DELTA,FREQ(1),FREQ(2),RTEMP
  290       FORMAT (5F10.2)
C
C     ****************************************************************
C     *                                                              *
C     *     NORMAL IS THE SUBROUTINE THAT GENERATES GAUSSIAN NOISE.  *
C     *     HERE, IT IS CALLED JUST TO INITIALIZE.                   *
C     *                                                              *
C     ****************************************************************
C
            CALL NORMAL (ERROR)
C
C           RCS IS THE REAL SPEED OF SOUND.
C
            RCS=331.36+0.6096*RTEMP
            RETURN
            END
```

NOL FORTRAN DIAGNOSTIC RESULTS - FOR   INPUT

NO ERRORS

DATA VARIABLES

ALA	00001				
ALR	00006	00014			
ALROT	00003				
ASAVE	00005				
AT	00001				
BINS	00006				
BT	00001				
CS	00001				
CT	00001				
DELTA	00006	00036			
FREQ	00006	00036	00036		
IFLAG	00003				
INCSAVE	00005				
JFLAG	00003				
KFLAG	00008				
M	00008				
MFLAG	00006				
NPASS	00008				
NREP	00005	00012			
NRUN	00006				
NRUNX	00006				
NSEN	00003	00029	00031		
NTRG	00001	00022	00024		
NUM	00006	00015	00016	00018	00018
PI	00007	00009	00027	00034	
PI2	00007	00011			
PID2	00007	00010			
RALA	00002	00027			
RALROT	00004	00034			
RANGE	00006	00036			
RCS	00002	00039			
RTA	00002	00025			
RTEMP	00002	00036	00039		
RVA	00002	00025			
RX0	00004	00032			
RXA	00002	00025			
RY0	00004	00032			
RYA	00002	00025			
RZA	00002	00025			
SAVE	00006	00016			
SNCPA	00006				
TA	00001				
TEMP	00001				
TLR	00006	00013			
TSAVE	00005				
VA	00001				
WSAVE	00005				
X0	00003				
XA	00001				
XK	00006				
XMEAN	00006				
Y0	00003				

```
        YA                              00001
        ZA                              00001

    COMMON VARIABLES

        **NONE**

    PROGRAM VARIABLES

        ERROR                           00038
        I                               00016    00016
        NORMAL                          00038
        NOYES                           00016    00019
        NS                              00031    00032    00032    00034
        NT                              00024    00025    00025    00025    00025
        RALAD                           00025    00027
        RALROTD                         00032    00034
```

SENCHK DECK/ L.R.X

```
00000                 SUBROUTINE SENCHK (NS,TAU,NT)
            C
            C     ***************************************************************
            C     *                                                             *
            C     *     JONATHAN VALVANO                                03/18/75 *
            C     *                                                             *
            C     *     THIS ROUTINE CHECKS TO SEE IF THE SENSOR SHOULD         *
            C     *     REPORT AT THIS TIME. IF IT DECIDES TO REPORT THEN IT MAKES *
            C     *     THE APPROPRIATE ENTRIES INTO THE ARRAYS. (TSAVE,ASAVE,WSAVE*
            C     *                                                             *
            C     ***************************************************************
            C
00001                 COMMON /RTRGT// RALA(3),RXA(3),RYA(3),RZA(3),
00001            1    RTA(3),RVA(3),RTEMP,PCS
00002                 COMMON /RSEN// RX0(3),RY0(3),RALHOT(3)
00003                 COMMON /REP// TSAVE(3,3,50),ASAVE(3,3,50),WSAVE(3,3,50),
00003            1    NREP(3,3),INCSAVE(3,3)
00004                 COMMON /STATE// TLR(3),ALR(3),MFLAG(3),FREQ(2),
00004            1    BINS,XMEAN,XK,SNCPA,RANGE,DELTA,NUM,NRUN,NRUNX,SAVE(10,100)
00005                 COMMON /CONST// PI,PID2,PI2
            C
            C     ***************************************************************
            C     *                                                             *
            C     *     THE SENSOR CAN ONLY REPORT EVERY FREQ(1) SECONDS IF THE *
            C     *     TARGET IS CHANGING BINS. IF IT HAS NOT BEEN AT LEAST    *
            C     *     FREQ(1) SECONDS, CONTROL IS RETURNED TO SIMULATE,       *
            C     *     AND THE SENSOR DOES NOT REPORT.                         *
            C     *                                                             *
            C     ***************************************************************
            C
00006                 IF ((TAU-TLR(NS)) .LT. FREQ(1)) RETURN
            C
            C     ***************************************************************
            C     *                                                             *
            C     *     TIME TAU IS WHEN THE SOUND ORIGINATES FROM THE TARGET.  *
            C     *     RXTAU=REAL X POSITION OF THE TARGET AT TIME TAU.        *
            C     *     RYTAU=REAL Y POSITION OF THE TARGET AT TIME TAU.        *
            C     *     RALTAU=REAL ALPHA ANGLE TO THE TARGET AT TIME TAU.      *
            C     *                                                             *
            C     ***************************************************************
            C
00008                 RXTAU=RXA(NT)+RVA(NT)*(TAU-RTA(NT))*COS(PID2-RALA(NT))
00009                 RYTAU=RYA(NT)+RVA(NT)*(TAU-RTA(NT))*SIN(PID2-RALA(NT))
00010                 RALTAU=PID2  -ATAN((RYTAU-RY0(NS))/(RXTAU-RX0(NS)))
00011                 IF (RXTAU .LT. RX0(NS)) RALTAU=RALTAU+PI
            C
            C     ***************************************************************
            C     *                                                             *
            C     *     DXYZ IS THE DISTANCE FROM THE SENSOR TO THE TARGET. IT IS *
            C     *     THIS DISTANCE THAT THE SOUND TRAVELS (FROM TARGET TO SENSOR*
            C     *                                                             *
            C     ***************************************************************
            C
00013                 DXYZ=SQRT((RXTAU-RX0(NS))**2+(RYTAU-RY0(NS))**2+RZA(NT)**2)
```

```
              C
              C     ****************************************************************
              C     *                                                              *
              C     *     IF THE TARGET IS OUT OF RANGE FOR THIS SENSOR,           *
              C     *     SET MFLAG TO 1 AND RETURN.    NO REPORT.                 *
              C     *                                                              *
              C     ****************************************************************
              C
00014                 IF (DXYZ .LT. RANGE) GO TO 300
00016                 MFLAG(NS)=1
00017                 RETURN
00018           300   MFLAG(NS)=0
              C
              C     ****************************************************************
              C     *                                                              *
              C     *     TIME IS THE TIME WHEN THE SOUND REACHS THE SENSOR.       *
              C     *     IT IS THE REPORT TIME.                                   *
              C     *                                                              *
              C     ****************************************************************
              C
00019                 TIME=TAU+DXYZ/RCS
              C
              C     ****************************************************************
              C     *                                                              *
              C     *     ALTAU WILL BE THE REPORT BEARING                         *
              C     *                                                              *
              C     ****************************************************************
              C
00020                 ALTAU=RALTAU+RALROT(NS)
              C
              C     ****************************************************************
              C     *                                                              *
              C     *     CALCULATE SIGNAL/NOISE (SN)                              *
              C     *                                                              *
              C     *     ADD GAUSSIAN ERROR.                                      *
              C     *                                                              *
              C     ****************************************************************
              C
00021                 SN=SNCPA/(DXYZ+1.0)
00022                 XSIGMA=XK/SQRT(SN)
00023                 CALL NORMAL (ERROR)
00024                 ALTAU=ALTAU+XMEAN+XSIGMA*ERROR
              C
              C     ****************************************************************
              C     *                                                              *
              C     *     ALTAU IS ADJUSTED TO FIT INTO A BEARING BIN.             *
              C     *                                                              *
              C     ****************************************************************
              C
00025                 ALTAU=(PI2/BINS)*FLOAT(IFIX(BINS*ALTAU/PI2+0.5))
              C
              C
              C
              C
```

```
      C
      C   ****************************************************************
      C   *                                                              *
      C   *     W IS THE WEIGHTING FACTOR PASSED FROM THE SENSOR.        *
      C   *                                                              *
      C   ****************************************************************
      C
                W=.001
      C
      C   ****************************************************************
      C   *                                                              *
      C   *     IF THE BEARING HAS NOT CHANGED SINCE THE LAST REPORT     *
      C   *     (ALTAU=ALR), THEN THE SENSOR MUST WAIT AT LEAST FREQ(2)  *
      C   *     SINCE THE LAST REPORT.  WE KNOW THE SENSOR HAS WAITED    *
      C   *     FREQ(1) SECONDS (FROM ABOVE), SO WE WILL REPORT IF EITHER *
      C   *               1. THE BEARING HAS CHANGED                     *
      C   *          OR   2. THE TIME DIFFERENCE .GT. FREQ(2)            *
      C   *                                                              *
      C   ****************************************************************
      C
                IF (( TAU-TLR(NS)) .LT. FREQ(2) .AND.
           1    ALTAU .EQ. ALR(NS)) RETURN
      C
      C   ****************************************************************
      C   *                                                              *
      C   *     THE SENSOR IS NOW REPORTING.                             *
      C   *                                                              *
      C   ****************************************************************
      C
                IF (NREP(NS,NT) .GE. 50) RETURN
                TLR(NS)=TAU
                ALR(NS)=ALTAU
                NREP(NS,NT)=NREP(NS,NT)+1
                N=NREP(NS,NT)
                TSAVE(NS,NT,N)=TIME
                ASAVE(NS,NT,N)=ALTAU
                WSAVE(NS,NT,N)=W
                RETURN
                END
```

NOL FORTRAN DIAGNOSTIC RESULTS - FOR SENCHK

NO ERRORS

DATA VARIABLES

ALR	00004	00027	00032		
ASAVE	00003	00036			
BINS	00004	00025	00025		
DELTA	00004				
FREQ	00004	00006	00027		
INCSAVE	00003				
MFLAG	00004	00016	00018		
NREP	00003	00029	00033	00033	00034
NRUN	00004				
NRUNX	00004				
NUM	00004				
PI	00005	00012			
PI2	00005	00025	00025		
PID2	00005	00008	00009	00010	
RALA	00001	00008	00009		
RALROT	00002	00020			
RANGE	00004	00014			
RCS	00001	00019			
RTA	00001	00008	00009		
RTEMP	00001				
RVA	00001	00008	00009		
RX0	00002	00010	00011	00013	
RXA	00001	00008			
RY0	00002	00010	00013		
RYA	00001	00009			
RZA	00001	00013			
SAVE	00004				
SNCPA	00004	00021			
TLR	00004	00006	00027	00031	
TSAVE	00003	00035			
WSAVE	00003	00037			
XK	00004	00022			
XMEAN	00004	00024			

COMMON VARIABLES

NONE

PROGRAM VARIABLES

ALTAU	00020	00024	00024	00025	00025
ATAN	00010				
COS	00008				
DXYZ	00013	00014	00019	00021	
ERROR	00023	00024			
FLOAT	00025				
IFIX	00025				
N	00034	00035	00036	00037	
NORMAL	00023				
NS	00000	00006	00010	00010	00011

	00020	00027	00027	00029	00031
	00035	00036	00037		
NT	00000	00008	00008	00008	00008
	00013	00029	00033	00033	00034
RALTAU	00010	00012	00012	00020	
RXTAU	00008	00010	00011	00013	
RYTAU	00009	00010	00013		
SIN	00009				
SN	00021	00022			
SQRT	00013	00022			
TAU	00000	00006	00008	00009	00019
TIME	00019	00035			
W	00026	00037			
XSIGMA	00022	00024			

OUTPUT DECK/ L.R.X

NOL FORTRAN (1.0)

```
00000          SUBROUTINE OUTPUT
      C
      C    ***************************************************************
      C    *                                                             *
      C    *    JONATHAN VALVANO                                03/16/75 *
      C    *                                                             *
      C    *    THIS ROUTINE OUTPUTS RESULTS.                            *
      C    *    ALL ANGLE OUTPUTS ARE IN DEGREES.                        *
      C    *                                                             *
      C    ***************************************************************
      C
00001          COMMON /TRGT// ALA(3),XA(3),YA(3),ZA(3),
00001        1 TA(3),VA(3),AT(3),BT(3),CT(3),TEMP,CS,NTRG
00002          COMMON /RTRGT// RALA(3),RXA(3),RYA(3),RZA(3),
00002        1 RTA(3),RVA(3),RTEMP,RCS
00003          COMMON /SEN// NSEN,X0(3),Y0(3),ALROT(3),IFLAG,JFLAG
00004          COMMON /RSEN// RX0(3),RY0(3),RALROT(3)
00005          COMMON /REP// TSAVE(3,3,50),ASAVE(3,3,50),WSAVE(3,3,50),
00005        1 NREP(3,3),INCSAVE(3,3)
00006          COMMON /STATE// TLR(3),ALR(3),MFLAG(3),FREQ(2),
00006        1 BINS,XMEAN,XK,SNCPA,RANGE,DELTA,NUM,NRUN,NRUNX,SAVE(10,100)
00007          COMMON /OPTIONS// KFLAG,M,NPASS
00008          COMMON /CONST// PI,PID2,PI2
00009          PRINT 604, NRUNX
00010     604  FORMAT (1H1,50X,5HRUN   ,I5)
00011          IF (KFLAG .EQ. 0) PRINT 611
00013     611  FORMAT (1H3,10X,15HBIAS CALCULATED)
00014          IF (KFLAG .EQ. 1) PRINT 612
00016     612  FORMAT (1H3,10X,12HBIAS INPUTED)
00017          PRINT 615
00018     615  FORMAT (1H ,10X,14HREPORTED   W=1,17X,
00018        1 32HCALCULATED W=EXP(-(RXY/1000)**2))
00019          PRINT 614, NPASS,M
00020     614  FORMAT (1H ,10X,18HNUMBER OF PASSES  ,I8,5X,
00020        1 21HINCREMENT FACTOR M    ,I8)
00021          XMEAND=XMEAN*180.0/PI
00022          PRINT 602,XMEAND,RANGE
00023     602  FORMAT (1H ,10X,4HMEAN,14X,F8.1,5X,5HRANGE,16X,F8.0)
00024          PRINT 603, XK,SNCPA
00025     603  FORMAT (1H ,10X,8HK FACTOR,10X,F8.4,5X,10HS/N AT CPA,11X,F8.0)
00026          PRINT 600, FREQ(1),FREQ(2)
00027     600  FORMAT (1H ,10X,18HCHANGE CYCLE TIME ,F8.2,
00027        1 5X,21HNO CHANGE CYCLE TIME ,F8.2)
00028          PRINT 601, BINS,DELTA
00029     601  FORMAT (1H ,10X,18HNUMBER OF BINS    ,F8.0,5X,
00029        1 21HTIME INCREMENT       ,F8.2)
      C
      C
      C
      C
      C
      C
      C
      C
```

```
C
            DO 610 NT=1,NTRG
            PRINT 605, NT
  605       FORMAT (1H3,10X,5HTARG ,I5,
     1      56H      XA        YA        ZA        VA  COURSE     TEMP       CS)
            RALAU=RALA(NT)*180.0/PI
            PRINT 606, RXA(NT),RYA(NT),RZA(NT),RVA(NT),RALAD,RTEMP,RCS
  606       FORMAT (1H ,10X,10HREAL      ,7F8.2)
            ALAU=ALA(NT)*180.0/PI
            PRINT 607, XA(NT),YA(NT),ZA(NT),VA(NT),ALAD,TEMP,CS
  607       FORMAT (1H ,10X,10HINPUTED   ,7F8.2)
  610       CONTINUE
            DO 650 NS=1,NSEN
            PRINT 620, NS
  620       FORMAT (1H3,10X,14HSENSOR NUMBER ,I5)
            PRINT 621
  621       FORMAT (1H ,10X,20X,
     1      36H           X0          Y0        ALROT)
            RALROTD=RALROT(NS)*180.0/PI
            PRINT 622, RX0(NS),RY0(NS),RALROTD
  622       FORMAT (1H ,10X,4HREAL,16X,3F12.5)
            ALROTD=ALROT(NS)*180.0/PI
            PRINT 623, X0(NS),Y0(NS),ALROTD
  623       FORMAT (1H ,10X,10HCALCULATED,10X,3F12.5)
            DX=RX0(NS)-X0(NS)
            DY=RY0(NS)-Y0(NS)
            DAL=RALROTD-ALROTD
            PRINT 624, DX,DY,DAL
  624       FORMAT (1H ,10X,10HDIFFERENCE,10X,3F12.5)
            DR=SQRT(DX**2+DY**2)
            PRINT 625, DR
  625       FORMAT (1H0,10X,12HRADIAL ERROR,8X,F12.5)
            PRINT 616, (INCSAVE(NS,I), I=1,3)
  616       FORMAT (1H ,10X,10HINCREMENTS,10X,3I12)
  650       CONTINUE
            RETURN
            END
```

NOL FORTRAN DIAGNOSTIC RESULTS - FOR OUTPUT

NO ERRORS

DATA VARIABLES

ALA	00001	00036			
ALR	00006				
ALROT	00003	00048			
ASAVE	00005				
AT	00001				
BINS	00006	00028			
BT	00001				
CS	00001	00037			
CT	00001				
DELTA	00006	00028			
FREQ	00006	00026	00026		
IFLAG	00003				
INCSAVE	00005	00059			
JFLAG	00003				
KFLAG	00007	00011	00014		
M	00007	00019			
MFLAG	00006				
NPASS	00007	00019			
NREP	00005				
NRUN	00006				
NRUNX	00006	00009			
NSEN	00003	00040			
NTRG	00001	00030			
NUM	00006				
PI	00008	00021	00033	00036	00045
PI2	00008				
PID2	00008				
RALA	00002	00033			
RALROT	00004	00045			
RANGE	00006	00022			
RCS	00002	00034			
RTA	00002				
RTEMP	00002	00034			
RVA	00002	00034			
RX0	00004	00046	00051		
RXA	00002	00034			
RY0	00004	00046	00052		
RYA	00002	00034			
RZA	00002	00034			
SAVE	00006				
SNCPA	00006	00024			
TA	00001				
TEMP	00001	00037			
TLR	00006				
TSAVE	00005				
VA	00001	00037			
WSAVE	00005				
X0	00003	00049	00051		
XA	00001	00037			
XK	00006	00024			
XMEAN	00006	00021			
Y0	00003	00049	00052		

YA	00001	00037			
ZA	00001	00037			

COMMON VARIABLES

NONE

PROGRAM VARIABLES

ALAD	00036	00037			
ALROTD	00048	00049	00053		
DAL	00053	00054			
DR	00056	00057			
DX	00051	00054	00056		
DY	00052	00054	00056		
I	00059	00059			
NS	00040	00041	00045	00046	00046
	00051	00052	00052	00059	
NT	00030	00031	00033	00034	00034
	00037	00037	00037		
RALAD	00033	00034			
RALROTD	00045	00046	00053		
SQRT	00056				
XMEAND	00021	00022			

SPL DECK/ L.R.X

```
      SUBROUTINE SPL(NS)
C
C
C   ***********************************************************************
C   *                                                                     *
C   *    JONATHAN VALVANO                                       03/18/75  *
C   *                                                                     *
C   *                                                                     *
C   *    THIS IS THE SENSOR POSITION LOCATOR ROUTINE.                     *
C   *                                                                     *
C   *                                                                     *
C   *    INPUTS                  NS         NUMBER OF SENSOR              *
C   *                            NPASS      NUMBER OF PASSES USED         *
C   *                            NTRG       NUMBER OF TARGETS             *
C   *                            TSAVE(NS,NT,NR)=TIME OF REPORT           *
C   *                            ASAVE(NS,NT,NR)=ANGLE OF REPORT          *
C   *                            WSAVE(NS,NT,NR)=W OF REPORT              *
C   *                            NREP(NS,NT)=NUMBER OF REPORTS            *
C   *                                                                     *
C   *    OUTPUTS                 X0(NS)     X POSITION OF THE SENSOR      *
C   *                            Y0(NS)     Y POSITION OF THE SENSOR      *
C   *                            ALROT(NS)  ANGLE ROTATION BIAS           *
C   *                                                                     *
C   *                                                                     *
C   *    GIVEN THE REPORTS SAVED IN THE ARRAYS THIS ROUTINE               *
C   *    CALCULATES THE SENSOR POSITION AND BIAS ANGLE.                   *
C   *    THE BIAS IS THE FIRST THING CALCULATED. IT USES THREE            *
C   *    REPORTS AND USING  ANGLE DIFFERENCES CALCULATES THE BIAS.        *
C   *    THE SENSOR POSITION  IS CALCULATED BY  A LEAST  SQUARES          *
C   *    FIT OF A POINT TO THE MANY LINES (ONE FOR EACH REPORT)           *
C   *    FROM THE TARGET TO THE SENSOR.                                   *
C   *    ENTER CALCULATES THESE LINES AND MAKES THE APPROPRIATE           *
C   *    SUMS INTO AI2,BI2,AIBI,AICI,BICI.  THE SENSOR POSITION           *
C   *    IS A SIMPLE RELATION OF THESE VARIABLES.                         *
C   *                                                                     *
C   *    THERE IS THE POSSIBILITY OF INPUTED THE BIAS (ALROT.)            *
C   *    IF THIS OPTION IS TAKEN, KFLAG SHOULD BE SET (KFLAG=1).          *
C   *    IF KLAG IS RESET (KFLAG=0) THEN THE PROGRAM WILL CALCULATE       *
C   *    ITS OWN BIAS.                                                    *
C   *                                                                     *
C   ***********************************************************************
C
      COMMON /TRGT// ALA(3),XA(3),YA(3),ZA(3),TA(3),VA(3),
     1 AT(3),BT(3),CT(3),TEMP,CS,NTRG
      COMMON /SEN// NSEN,X0(3),Y0(3),ALROT(3),IFLAG,JFLAG
      COMMON /REP// TSAVE(3,3,50),ASAVE(3,3,50),WSAVE(3,3,50),
     1 NREP(3,3),INCSAVE(3,3)
      COMMON /CONST// PI,PID2,PI2
      COMMON /SUMS// AI2,BI2,AIBI,AICI,BICI
      COMMON /OPTIONS// KFLAG,M,NPASS
C
C
C
C
```

```
      C   ***********************************************************
      C   *                                                         *
      C   *    WHEN CALCULATING THE BIAS IT IS BETTER NOT TO USE    *
      C   *    SEQUENCIAL REPORTS BECAUSE THE ANGLE DIFFERENCES ARE *
      C   *    EITHER TOO SMALL OR ZERO.  THEREFORE WE WILL INCREMENT *
      C   *    THROUGH THE ARRAYS  STEPPING MORE THAN ONE. INC IS THE *
      C   *    VALUE OF THE INCREMENT FOR EACH TARGET THE SENSOR SAW. *
      C   *    IF INC(1)=4 THEN WHEN WE LOOK AT THE REPORTS OF TARGET 1, *
      C   *    WE WILL STEP THROUGH BY 4 (1,5,9,13,...).            *
      C   *    IN ORDER TO USE AS MUCH OF THE DATA AS POSSIBLE.  WE *
      C   *    WILL STEP THROUGH THE ARRAYS AGAIN BUT STARTING WITH 2. *
      C   *    THEN 3.  THEN 4.  IF NREP(NS,1)=50 THEN INC(1) WOULD BE 13 *
      C   *    AND WE WOULD LOOK AT THE REPORTS IN THIS ORDER---    *
      C   *    1,14,27,40  2,15,28,41 3,16,29,41 ,... 13,26,39      *
      C   *    BIAS CALCULATIONS USE REPORTS IN GROUPS OF THREE.    *
      C   *    POSITION CALCULATION S USE EACH REPORT SEPERATELY.   *
      C   *                                                         *
      C   ***********************************************************
      C
            DO 400 NT=1,NTRG
            INCSAVE(NS,NT)=1+NREP(NS,NT)/M
        400 CONTINUE
      C
      C   ***********************************************************
      C   *                                                         *
      C   *    THE POSITION CALCULATION CAN NOT BE DONE WITHOUT  A BIAS *
      C   *    CALCULATION . BUT THE BIAS CALCULATION CAN BE DONE WITH *
      C   *    OR WITHOUT A POSITION CALCULATION . THE BIAS CALCULATION *
      C   *    IS MORE ACCURATE WHEN  POSITION IS KNOWN.  TO KEEP   *
      C   *    TRACK OF  WHICH CALCULATIONS HAVE BEEN DONE FLAGS    *
      C   *    ARE USED.          IFLAG=0   MEANS NO BIAS CALCULATION *
      C   *                       IFLAG=1   MEANS A BIAS CALCULATION *
      C   *                       JFLAG=0   MEANS NO POSITION CALCULATION*
      C   *                       JFLAG=1   MEANS A POSITION CALCULATION *
      C   *                       KFLAG=0   MEANS BIAS TO BE CALCULATED *
      C   *                       KFLAG=1   MEANS BIAS HAS BEEN INPUTED *
      C   *                                                         *
      C   ***********************************************************
        401 IFLAG=0
            JFLAG=0
            DO 490 NP=1,NPASS
      C   ***********************************************************
      C   *                                                         *
      C   *    EACH PASS STARTS WITH FRESH  SUMS BUT USES THE CALCULATIONS*
      C   *    FROM THE PREVIOUS PASS.                              *
      C   *                                                         *
      C   ***********************************************************
            AI2=0.0
            BI2=0.0
            AIBI=0.0
            AICI=0.0
            BICI=0.0
            BSI=0.0
            WI=0.0
```

```
        C
        C
        C
        C   ****************************************************************
        C   *                                                              *
        C   *     IF DATA FROM TWO OR MORE TARGETS IS AVAILABLE THEN       *
        C   *     CALCULATIONS ARE GENERALLY MORE ACCURATE.                *
        C   *     HERE, WE LOOP THROUGH FOR EACH TARGET.                   *
        C   *                                                              *
        C   ****************************************************************
        C
        C
        C
00020             DO 480 NT=1,NTRG
        C
        C
        C   ****************************************************************
        C   *                                                              *
        C   *     NRPT IS THE NUMBER OF REPORTS  OF THIS TARGET.           *
        C   *     N  IS THE INCREMENT USED  WITH THE REPORTS OF THIS TARGET. *
        C   *                                                              *
        C   ****************************************************************
        C
        C
        C
00021             NRPT=NREP(NS,NT)
00022             N=INCSAVE(NS,NT)
        C
        C   ****************************************************************
        C   *                                                              *
        C   *     IF WE ARE GOING TO INCREMENT BY N THEN THERE MUST BE     *
        C   *     AT LEAST 3*N POINTS IN THE ARRAYS ,IF NOT GO TO NEXT TARGET*
        C   *                                                              *
        C   ****************************************************************
        C
00023             IF (NRPT .LT. 3*N) GO TO 480
        C
        C
        C
        C
        C
        C
        C
        C
        C
        C
        C
        C
        C
        C
        C
        C
        C
        C
        C
        C
```

```
C
C
      DO 470 NFIRST=1,N
C
C
C     ***************************************************************
C     *                                                             *
C     *                                                             *
C     *    N1 IS THE NUMBER OF THE FIRST REPORT.                    *
C     *    N2 IS THE NUMBER OF THE SECOND REPORT.                   *
C     *    N3 IS THE NUMBER OR THE THIRD REPORT..                   *
C     *                                                             *
C     *    T1 IS THE TIME OF THE FIRST REPORT.                      *
C     *    T2 IS THE TIME OF THE SECOND REPORT.                     *
C     *    T3 IS THE TIME OF THE THIRD REPORT .                     *
C     *                                                             *
C     *    (X1,Y1) IS THE TARGET POSITION AT THE FIRST REPORT.      *
C     *    (X2,Y2) IS THE TARGET POSITION AT THE SECOND REPORT.     *
C     *    (X3,Y3) IS THE TARGET POSITION AT THE THIRD REPORT.      *
C     *                                                             *
C     *    ALPHA1 IS THE REPORTED BEARING OF THE FIRST REPORT.      *
C     *    ALPHA2 IS THE REPORTED BEARING OF THE SECOND REPORT.     *
C     *    ALPHA3 IS THE REPORTED BEARING OF THE THIRD REPORT.      *
C     *                                                             *
C     *    W1 IS THE WEIGHTING FACTOR ASSOCIATED WITH THE FIRST REPORT*
C     *    W2 IS THE WEIGHTING FACTOR ASSOCIATED WITH THE SECOND REPORT*
C     *    W3 IS THE WEIGHTING FACTOR ASSOCIATED WITH THE THIRD REPORT*
C     *                                                             *
C     *    THETA1 IS THE ANGLE DIFFERENCE BETWEEN FIRST AND SECOND  *
C     *    THETA2 IS THE ANGLE DIFFERENCE BETWEEN THE SECOND AND THIRD*
C     *                                                             *
C     *    D12 IS THE DISTANCE TRAVELLED BETWEEN  THE FIRST AND SECOND*
C     *    D23 IS THE DISTANCE TRAVELLED BETWEEN THE SECOND AND THIRD *
C     *                                                             *
C     *                                                             *
C     ***************************************************************
C
C
      N1=NFIRST
      N2=N1+N
      NSTART=N2+N
      CALL ENTER (NS,NT,N1,T1,X1,Y1,ALPHA1,W1)
      CALL ENTER (NS,NT,N2,T2,X2,Y2,ALPHA2,W2)
      IF (KFLAG .EQ. 1) GO TO 410
      D12=SQRT((X1-X2)**2+(Y1-Y2)**2)
      THETA1=ALPHA2-ALPHA1
C
C     ***************************************************************
C     *                                                             *
C     *    SHIFT WILL SHIFT THETA1 BETWEEN -PI AND +PI              *
C     *                                                             *
C     ***************************************************************
C
      CALL SHIFT (THETA1,0.0)
```

```
C
C
C     *************************************************************
C     *                                                           *
C     *                                                           *
C     *     THE BIAS ALGORITHM WILL NOT WORK IF THETA1 EQUALS ZERO.   *
C     *     THE INCREMENT IS INCREASED AND WE START OVER AGAIN.       *
C     *                                                           *
C     *                                                           *
C     *************************************************************
C
C
      IF (THETA1 .NE. 0.0) GO TO 410
      INCSAVE(NS,NT)=INCSAVE(NS,NT)+1
      GO TO 401
  410 DO 460 N3=NSTART,NRPT,N
      CALL ENTER (NS,NT,N3,T3,X3,Y3,ALPHA3,W3)
      IF (KFLAG .EQ. 1) GO TO 460
      D23=SQRT((X3-X2)**2+(Y3-Y2)**2)
      THETA2=ALPHA3-ALPHA2
C
C
C     *************************************************************
C     *                                                           *
C     *     SHIFT WILL SHIFT THETA2 BETWEEN -PI AND +PI               *
C     *                                                           *
C     *************************************************************
C
C
      CALL SHIFT (THETA2,0.0)
C
C
C     *************************************************************
C     *                                                           *
C     *                                                           *
C     *     THE ALGORITHM WILL NOT WORK IF                        *
C     *              THETA1 EQUALS ZERO                           *
C     *              THETA2 EQUALS ZERO                           *
C     *              THETA1 AND THETA2 HAVE OPPOSITE SIGNS.       *
C     *     IF ANY OF THESE FAULTS OCCUR THE ALGORITM IS SKIPPED.  *
C     *                                                           *
C     *                                                           *
C     *************************************************************
C
C
      IF (THETA1*THETA2 .LE. 0.0) GO TO 460
C
C
C
C
C
C
C
C
```

```
      C
      C
      C     ***************************************************************
      C     *                                                             *
      C     *                                                             *
      C     *     THIS IS THE BIAS CALCULATION.                           *
      C     *                                                             *
      C     *                                                             *
      C     ***************************************************************
      C
            THETA12=THETA1+THETA2
            DENOM=D12*SIN(THETA2)/(D23*SIN(THETA1))-COS(THETA12)
            PHI=ATAN(SIN(THETA12)/DENOM)
            IF (DENOM .LT. 0.0) PHI=PHI+PI
            BS=PI+ALPHA1-ALA(NT)-PHI
      C
      C     ***************************************************************
      C     *                                                             *
      C     *     SHIFT WILL SHIFT BS BTWEEN (ALROT-PI) AND (ALROT+PI)    *
      C     *                                                             *
      C     *     EACH BIAS CALCULATION (BS) IS AVERAGED INTO BSI WITH A  *
      C     *     WEIGHTING FACTOR OF W2.                                 *
      C     *                                                             *
      C     ***************************************************************
      C
            CALL SHIFT (BS,ALROT(NS))
            BSI=BSI+W2*BS
            WI=WI+W2
      C
      C     ***************************************************************
      C     *                                                             *
      C     *     THIS FOLLOWING VARIABLES ARE BUMPED DOWN SO             *
      C     *     THEY WILL NOT HAVE TO BE RECALCULATED.                  *
      C     *                                                             *
      C     ***************************************************************
      C
            N1=N2
            N2=N3
            X2=X3
            Y2=Y3
            THETA1=THETA2
            ALPHA1=ALPHA2
            ALPHA2=ALPHA3
            D12=D23
            W2=W3
        460 CONTINUE
      C
      C
      C
      C
      C
      C
      C
```

```
C
C     ****************************************************************
C     *                                                              *
C     *     WE HAVE NOW FINISHED ONE LOOP THROUGH THE ARRAYS.        *
C     *     CONTROL WILL BE HERE ABOUT INC(NT) TIMES FOR EACH        *
C     *     TARGET AND FOR EACH PASS AND FOR EACH SENSOR.            *
C     *                                                              *
C     ****************************************************************
C
C     ****************************************************************
C     *                                                              *
C     *     IF WI EQUALS ZERO THAT MEANS NO BIAS CALCULATIONS HAVE   *
C     *     BEEN DONE. IF THIS IS SO THEN NO AVERAGING CAN BE DONE.  *
C     *                                                              *
C     ****************************************************************
C
            IF (WI .EQ. 0.0 .OR. KFLAG .EQ. 1) GO TO 465
C
C     ****************************************************************
C     *                                                              *
C     *     CALCULATE THE AVERAGE BIAS AND SET IFLAG.                *
C     *                                                              *
C     ****************************************************************
C
            ALROT(NS)=RSI/WI
            IFLAG=1
C
  465       DENOM=AI2*BI2-AIBI**2
C
C     ****************************************************************
C     *                                                              *
C     *     IF DENOM EQUALS ZERO THEN WE HAVE CALCULATED ONLY ONE OR *
C     *     NO LINES THROUGH THE SENSOR. IN EITHER CASE A SENSOR     *
C     *     POSITION CALCULATION CAN NOT BE DONE AND IS SKIPPED.     *
C     *                                                              *
C     ****************************************************************
C
            IF (DENOM .EQ. 0.0) GO TO 470
C
C     ****************************************************************
C     *                                                              *
C     *     THE SENSOR POSITION LOCATION IS CALCULATED. AND JFLAG SET. *
C     *                                                              *
C     ****************************************************************
C
            X0(NS)=(BICI*AIBI-AICI*BI2)/DENOM
            Y0(NS)=(AICI*AIBI-BICI*AI2)/DENOM
            JFLAG=1
  470       CONTINUE
  480       CONTINUE
  490       CONTINUE
            RETURN
            END
```

NOL FORTRAN DIAGNOSTIC RESULTS - FOR   SPL

NO ERRORS

DATA VARIABLES

AI2	00005	00013	00072	00076	
AIBI	00005	00015	00072	00075	00075
AICI	00005	00016	00075	00076	
ALA	00001	00054			
ALROT	00002	00055	00070		
ASAVE	00003				
AT	00001				
BI2	00005	00014	00072	00075	
BICI	00005	00017	00075	00076	
BT	00001				
CS	00001				
CT	00001				
IFLAG	00002	00010	00071		
INCSAVE	00003	00008	00022	00038	00039
JFLAG	00002	00011	00077		
KFLAG	00006	00031	00042	00068	
M	00006	00008			
NPASS	00006	00012			
NREP	00003	00008	00021		
NSEN	00002				
NTRG	00001	00007	00020		
PI	00004	00053	00054		
PI2	00004				
PID2	00004				
TA	00001				
TEMP	00001				
TSAVE	00003				
VA	00001				
WSAVE	00003				
X0	00002	00075			
XA	00001				
Y0	00002	00076			
YA	00001				
ZA	00001				

COMMON VARIABLES

NONE

PROGRAM VARIABLES

ALPHA1	00029	00034	00054	00063	
ALPHA2	00030	00034	00045	00063	00064
ALPHA3	00041	00045	00064		
ATAN	00051				
BS	00054	00055	00056		
BSI	00018	00056	00056	00070	
COS	00050				
D12	00033	00050	00065		
D23	00044	00050	00065		

DENOM	00050	00051	00052	00072	00073
ENTER	00029	00030	00041		
N	00022	00023	00025	00027	[illegible]
N1	00026	00027	00029	[illegible]	
N2	00027	00028	00030	00058	00059
N3	00040	00041	00059		
NFIRST	00025	00026			
NP	00012				
NRPT	00021	00023	00040		
NS	00000	00008	00008	00021	00022
	00041	00055	00070	00075	00076
NSTART	00028	00040			
NT	00007	00008	00008	00020	00021
	00038	00041	00054		
PHI	00051	00053	00053	00054	
SHIFT	00035	00046	00055		
SIN	00050	00050	00051		
SQRT	00033	00044			
T1	00029				
T2	00030				
T3	00041				
THETA1	00034	00035	00036	00047	00049
THETA12	00049	00050	00051		
THETA2	00045	00046	00047	00049	00050
W1	00029				
W2	00030	00056	00057	00066	
W3	00041	00066			
WI	00019	00057	00057	00068	00070
X1	00029	00033			
X2	00030	00033	00044	00060	
X3	00041	00044	00060		
Y1	00029	00033			
Y2	00030	00033	00044	00061	
Y3	00041	00044	00061		

AD-A032 850 NAVAL SURFACE WEAPONS CENTER WHITE OAK LAB SILVER SP--ETC F/G 17/1
SENSOR POSITION LOCATOR.(U)
SEP 75 J VALVANO
UNCLASSIFIED NSWC/WOL/TR 76-8 NL

2 OF 2
AD
A032850

END
DATE
FILMED
1-77

ENTER DECK/ L.R.X

NOL FORTRAN (1.0)

```
00000               SUBROUTINE ENTER (NS,NT,NR,T,XT,YT,ALPHA,W)
          C
          C
          C     ***************************************************************
          C     *                                                             *
          C     *   JONATHAN VALVANO                                 03/18/75 *
          C     *                                                             *
          C     *                                                             *
          C     *   ENTER IS THE ROUTINE THAT CALCULATES THE LINE FROM        *
          C     *   THE TARGET TO THE SENSOR AND MAKES THE APPROPRIATES SUMS  *
          C     *   USED IN THE SPL ALGORITHM.                                *
          C     *                                                             *
          C     *                                                             *
          C     *   INPUTS    NS THE NUMBER OF THE SENSOR                     *
          C     *   NT IS THE NUMBER OF THE TARGET                            *
          C     *   NR THE NUMBER OF THE REPORT                               *
          C     *   TSAVE(NS,NT,NR) THE TIME OF THIS REPORT                   *
          C     *   ASAVE(NS,NT,NR) THE BEARING OF THE REPORT                 *
          C     *   WSAVE(NS,NT,NR) THE WEIGHTING FACTOR PASSED BY THE SENSOR *
          C     *   AT,BT,CT WHICH FORM THELINE AT*X+BT*Y+CT=0 OF TARGET TRACK*
          C     *   ZA(NT) WHICH IS THE TARGETS ALTITUDE                      *
          C     *   TXY WHICH RETURNS THE TARGETS POSITION AS A FUNCTION OF T *
          C     *   ALROT WHICH  IS THE SENSORS ANGLE ROTATION BIAS           *
          C     *                                                             *
          C     *                                                             *
          C     *   OUTPUTS   T THE TIME OF THE REPORT                        *
          C     *   XT,YT THE POSITION OF THE TARGET AT THE TIME OF THE REPORT*
          C     *   ALPHA THE REPORT BEARING (CORRECTED FOR THE SPEED OF SOUND)*
          C     *   W THE COMBINED WEIGHTING FACTOR REPORTED AND CALCULATED   *
          C     *   SUMS IN AI2,BI2,AIBI,AICI,BICI  FOR SPL ALGORITHM         *
          C     *                                                             *
          C     *                                                             *
          C     ***************************************************************
          C
          C     ***************************************************************
          C     *                                                             *
          C     *                                                             *
          C     *   THESE ARE THE COMMON STATEMENTS.                          *
          C     *                                                             *
          C     ***************************************************************
          C
00001               COMMON /TRGT// ALA(3),XA(3),YA(3),ZA(3),TA(3),VA(3),
00001          1    AT(3),BT(3),CT(3),TEMP,CS,NTRG
00002               COMMON /SEN// NSEN,X0(3),Y0(3),ALROT(3),IFLAG,JFLAG
00003               COMMON /REP// TSAVE(3,3,50),ASAVE(3,3,50),WSAVE(3,3,50),
00003          1    NREP(3,3),INCSAVE(3,3)
00004               COMMON /CONST// PI,PID2,PI2
00005               COMMON /SUMS// AI2,BI2,AIBI,AICI,BICI
00006               COMMON /OPTIONS// KFLAG,M,NPASS
          C
          C
          C
          C
          C
          C
```

```
      T=TSAVE(NS,NT,NR)
      ALPHA=ASAVE(NS,NT,NR)
      W=WSAVE(NS,NT,NR)
      CALL TXY (XT,YT,T,NT)
C
C     ************************************************************
C     *                                                          *
C     *    IF WE ARE GOING TO CALCULATE THE BIAS (KFLAG=0) AND   *
C     *    IF A BIAS CALCULATION HAS NOT BEEN DONE THEN RETURN   *
C     *                                                          *
C     ************************************************************
C
      IF (IFLAG .EQ. 0 .AND. KFLAG .EQ. 0) RETURN
C
C     ************************************************************
C     *                                                          *
C     *    THE RATIO IS USED IN THE ALGORITHM TO ACCOUNT FOR THE *
C     *    SPEED OF SOUND , THE TARGET SPEED (VA) MUST BE LESS THAN *
C     *    THE SPEED OF SOUND(CS). THIS ALONE CORRECTS ONLY THE  *
C     *    TWO DIMENSIONAL CASE. IF A SENSOR CALCULATION HAS BEEN *
C     *    DONE BEFORE (JFLAG=1) THEN THIS ALGORITHM CAN CORRECT *
C     *    THE THREE DIMENSIONAL CASE. IF NO SENSOR POSITION     *
C     *    LOCATION HAS BEEN DONE (JFLAG=0) THEN  JUST USE  THE 2-D. *
C     *                                                          *
C     ************************************************************
C
      BETA=PI+ALA(NT)-(ALPHA-ALROT(NS))
      RATIO=CS/VA(NT)
      RXYTAU=10000.0
      IF (JFLAG .EQ. 0) GO TO 500
C
C     ************************************************************
C     *                                                          *
C     *    (XP,YP) IS THE POINT ON THE TARGET TRACK AT CPA       *
C     *    THE POINT IS USED IN THE ALGORITHM TO CORRECT FOR THE *
C     *    SPEED OF SOUND DUE TO THE ALTITUDE.  THE RATIO IS     *
C     *    RECALCULATED  TAKING THE ALTITUDE INTO EFFECT.        *
C     *    RXYTAU IS THE TWO DIMENSIONAL RADIAL DISTANCE FROM    *
C     *    THE SENSOR TO THE TARGET AT TIME TAU (TIME WHEN THE SOUND *
C     *    ORIGINATED.)  RXYTAU IS USED TO CONSTRUCT A W.        *
C     *                                                          *
C     ************************************************************
C
      D=AT(NT)*YO(NS)-BT(NT)*XO(NS)
      DENOM=AT(NT)**2+BT(NT)**2
      XP=-(AT(NT)*CT(NT)+BT(NT)*D)/DENOM
      YP=(AT(NT)*D-BT(NT)*CT(NT))/DENOM
      RXYTAU=(SQRT((XO(NS)-XP)**2+(YO(NS)-YP)**2))/
     1 ABS(SIN(BETA))
      RATIO=RATIO*RXYTAU/SQRT(ZA(NT)**2+RXYTAU**2)
      IF (RXYTAU .GT. 5000.0) RXYTAU=5000.0
      W=1000.0*W*EXP(-(RXYTAU/1000.0)**2)
C
C
```

```
C     ****************************************************************
C     *                                                              *
C     *    THETA IS THE CORRECTION ANGLE DUE TO THE SPEED OF SOUND.  *
C     *    CALPHA IS THE CORECTED  REPORT BEARING.                   *
C     *    ALPHA  IS CORRECTED AND PASSED BACK TO THE BIAS ALGORITHM *
C     *                                                              *
C     *    CALPHA IS USED TO CALCULATE A,B,C OF THE LINE A*X+B*Y+C=0 *
C     *    THIS LINE GOES THROUGH THE SENSOR AND THE TAREGT          *
C     *    THE ALGORITHM WILL EVENTUALLY (INSPL)  FIND THE POINT     *
C     *    (X0,Y0)  WHICH MINIMIZES THE DISTANCE FROM THAT POINT     *
C     *    TO EACH LINE. A WEIGHTING FACTOR IS USED IN THE LEAST     *
C     *    SQUARES ALGORITHM.                                        *
C     *                                                              *
C     ****************************************************************
C
  500 THETA=ATAN(SIN(BETA)/(RATIO-COS(BETA)))
      CALPHA=(ALPHA-ALROT(NS))-THETA
      ALPHA=ALPHA-THETA
C
C     ****************************************************************
C     *                                                              *
C     *    CALCULATE A,B,C TO FORM THE LINE  A*X+B*Y+C=0             *
C     *                                                              *
C     ****************************************************************
C
      A=COS(CALPHA)
      B=-SIN(CALPHA)
      C=-(A*XT+B*YT)
C
C     ****************************************************************
C     *                                                              *
C     *    MAKE THE SUMS.                                            *
C     *                                                              *
C     ****************************************************************
C
      A2PB2=(A**2+B**2)*RXYTAU**2
      AI2=AI2+W*A**2/A2PB2
      BI2=BI2+W*B**2/A2PB2
      AIBI=AIBI+W*A*B/A2PB2
      AICI=AICI+W*A*C/A2PB2
      BICI=BICI+W*B*C/A2PB2
      RETURN
      END
```

NOL FORTRAN DIAGNOSTIC RESULTS - FOR   ENTER

NO ERRORS

```
DATA VARIABLES

     AI2          00005   00034   00034
     AIBI         00005   00036   00036
     AICI         00005   00037   00037
     ALA          00001   00013
     ALROT        00002   00013   00028
     ASAVE        00003   00008
     AT           00001   00018   00019   00020   00021
     BI2          00005   00035   00035
     BICI         00005   00038   00038
     BT           00001   00018   00019   00020   00021
     CS           00001   00014
     CT           00001   00020   00021
     IFLAG        00002   00011
     INCSAVE      00003
     JFLAG        00002   00016
     KFLAG        00006   00011
     M            00006
     NPASS        00006
     NREP         00003
     NSEN         00002
     NTRG         00001
     PI           00004   00013
     PI2          00004
     PIO2         00004
     TA           00001
     TEMP         00001
     TSAVE        00003   00007
     VA           00001   00014
     WSAVE        00003   00009
     XO           00002   00018   00022
     XA           00001
     YO           00002   00018   00022
     YA           00001
     ZA           00001   00023

COMMON VARIABLES

     **NONE**

PROGRAM VARIABLES

     A            00030   00032   00033   00034   00036
     A2PB2        00033   00034   00035   00036   00037
     ABS          00022
     ALPHA        00000   00008   00013   00028   00029
     ATAN         00027
     B            00031   00032   00033   00035   00036
     BETA         00013   00022   00027   00027
     C            00032   00037   00038
     CALPHA       00028   00030   00031
```

COS	00027	00030			
D	00018	00020	00021		
DENOM	00019	00020	00021		
EXP	00026				
NR	00000	00007	00008	00009	
NS	00000	00007	00008	00009	00013
	00028				
NT	00000	00007	00008	00009	00010
	00017	00019	00020	00020	00020
RATIO	00014	00023	00023	00027	
RXYTAU	00015	00022	00023	00023	00024
SIN	00022	00027	00031		
SQRT	00022	00023			
T	00000	00007	00010		
THETA	00027	00028	00029		
TXY	00010				
W	00000	00009	00026	00026	00034
XP	00020	00022			
XT	00000	00010	00032		
YP	00021	00022			
YT	00000	00010	00032		

SHIFT DECK/ L.R.X

NOL FORTRAN (1.0)

```
00000              SUBROUTINE SHIFT (ANGLE,BIAS)
             C
             C   ****************************************************************
             C   *                                                              *
             C   *     JONATHAN VALVANO                                 03/16/75 *
             C   *                                                              *
             C   *                                                              *
             C   *     THIS ROUTINE SHIFTS THE ANGLE BETWEEN                    *
             C   *     (BIAS-PI) TO (BIAS+PI)                                   *
             C   *                                                              *
             C   *                                                              *
             C   ****************************************************************
             C
00001              COMMON /CONST// PI,PIO2,PI2
             C
00002         800  IF (BIAS-PI .LT. ANGLE) GO TO 810
00004              ANGLE=ANGLE+PI2
00005              GO TO 800
00006         810  IF (BIAS+PI .GT. ANGLE) RETURN
00008              ANGLE=ANGLE-PI2
00009              GO TO 810
00010              END
```

NOL FORTRAN DIAGNOSTIC RESULTS - FOR   SHIFT

NO ERRORS

DATA VARIABLES

PI	00001	00002	00006		
PI2	00001	00004	00008		
PID2	00001				

COMMON VARIABLES

NONE

PROGRAM VARIABLES

ANGLE	00000	00002	00004	00004	00006
BIAS	00000	00002	00006		

TXY DECK/ L.R.X

NOL FORTRAN (1.0)

```
00000              SUBROUTINE TXY (X,Y,T,NT)
            C
            C
            C   ****************************************************************
            C   *                                                              *
            C   *      JONATHAN VALVANO                                03/18/75 *
            C   *                                                              *
            C   *                                                              *
            C          THIS ROUTINE CALCULATES THE TARGET POSITION.
            C          THE POSITION  IS THOUGHT TO BE TRUE.
            C   *                                                              *
            C   *                                                              *
            C   ****************************************************************
            C
00001              COMMON /TRGT// ALA(3),XA(3),YA(3),ZA(3),
00001         1    TA(3),VA(3),AT(3),BT(3),CT(3),TEMP,CS,NTRG
00002              COMMON /CONST// PI,PID2,PI2
00003              ANGLE=PID2-ALA(NT)
00004              DIST=VA(NT)*(T-TA(NT))
00005              X=XA(NT)+DIST*COS(ANGLE)
00006              Y=YA(NT)+DIST*SIN(ANGLE)
00007              RETURN
00008              END
```

NOL FORTRAN DIAGNOSTIC RESULTS - FOR   TXY

NO ERRORS

DATA VARIABLES

ALA	00001	00003			
AT	00001				
BT	00001				
CS	00001				
CT	00001				
NTRG	00001				
PI	00002				
PI2	00002				
PID2	00002	00003			
TA	00001	00004			
TEMP	00001				
VA	00001	00004			
XA	00001	00005			
YA	00001	00006			
ZA	00001				

COMMON VARIABLES

NONE

PROGRAM VARIABLES

ANGLE	00003	00005	00006		
COS	00005				
DIST	00004	00005	00006		
NT	00000	00003	00004	00004	00005
SIN	00005				
T	00000	00004			
X	00000	00005			
Y	00000	00006			

```
TXY       DECK/      L.R.X
NORMAL    DECK/      L.R.X                                              000
```

L FORTRAN (1.0)

```
      SUBROUTINE NORMAL(X)
C
C FORTRAN CALL LINE:
C
C     CALL NORMAL(X)
C
C THIS PROGRAM USES THE POLAR METHOD TO GENERATE NORMALLY DISTRIBUTED
C RANDOM NUMBERS OF ZERO MEAN AND UNIT VARIANCE.  THE NUMBERS ARE
C GENERATED TWO AT A TIME, SO EVERY OTHER CALL REQUIRES NO WORK.
C THE LOCAL INTEGER MODE VARIABLE M WILL NORMALLY NOT BE ONE AT LOAD
C TIME.  IF THIS IS NOT THE CASE FOR A PARTICULAR FORTRAN SYSTEM, THE
C USER CAN INITIALIZE THE PROGRAM VARIABLES BY MAKING AN INITIAL CALL
C AND DISREGAURDING THE RESULT.
C
C THE SUBROUTINE UNIFORM USED IN THE PROGRAM SHOULD GENERATE RANDOM
C NUMBERS UNIFORMLY DISTRIBUTED BETWEEN ZERO AND ONE.
C
      IF(M .EQ. 1) GO TO 20
      M=1
   10 CALL UNIFORM(Y)
      U1=2.*Y-1.
      CALL UNIFORM(Y)
      U2=2.*Y-1.
      S=U1*U1+U2*U2
      IF(S .GE. 1.) GO TO 10
      S=SQRTF(-2.*ALOG(S)/S)
      X=U1*S
      RETURN
   20 M=0
      X=U2*S
      RETURN
      END
```

NOL FORTRAN DIAGNOSTIC RESULTS - FOR   NORMAL

ERRORS

NOL FORTRAN (1.0)   SUBROUTINE NORMAL(X)

DATA VARIABLES

NONE

COMMON VARIABLES

NONE

PROGRAM VARIABLES

ALOG	00011				
M	00001	00003	00014		
S	00008	00009	00011	00011	[illegible]
SQRTF	00011				
U1	00005	00008	00009	00012	
U2	00007	00006	00008	00015	
UNIFORM	00004	00006			
X	00000	00012	00015		
Y	00004	00005	00006	.00007	

SCMP

```
NOL COMPASS (1.0)
  UNIFORM  DECK/      L,X
```

NOL COMPASS (1.0) UNIFORM

ENTRY POINT SYMBOLS
UNIFORM 00000

PROGRAM	00052
COMMON	
DATA	

```
                    ENTRY     UNIFORM

               FORTRAN CALL LINE:

                    CALL UNIFORM(X)

                    IF X IS GREATER THAN OR EQUAL TO ZERO WHEN THE CALL IS EXECUTED,
               X IS REPLACED WITH A RANDOM NUMBER UNIFORMLY DISTRIBUTED BETWEEN 0
               AND 1. THE COMPUTATION USES 35 BIT INTEGER ARITHMETIC, AND CONVERTS
               TO FLOATING POINT. THE ALGORITHM IS THE LINEAR CONGRUENTIAL
               METHOD WITH A MODULUS OF 2**35, A MULTIPLIER OF 5**15, AND AN
               INCREMENT OF 7261067085. THESE PARAMETERS HAVE BEEN EXTENSIVELY
               TESTED, AND YIELD A MAXIMUM LENGTH SEQUENCE WITH GOOD SPECTRAL
               PROPERTIES.

                    IF X IS LESS THAN ZERO WHEN THE CALL IS EXECUTED, -X IS
               CONVERTED TO A 35 BIT FIXED POINT FRACTION, AND THE MOST SIGNIFICANT
               35 BITS ARE USED TO INITIALIZE THE RANDOM NUMBER GENERATOR. IF -X IS
               GREATER THAN OR EQUAL TO 1 OR LESS THAN 2**-35, THE SEQUENCE WILL
               START WITH ZERO. THE STARTING VALUE IS CONVERTED TO FLOATING POINT
               AND RETURNED IN X, SO THAT X IS ALWAYS A FRACTION BETWEEN 0 AND 1 ON
               RETURN.

               ENTER, GET X, AND BRANCH TO INITIALIZATION IF NEGATIVE.

 77777 0  UNIFORM  UJP      **        ENTRY POINT
 P00000 1          LDI      UNIFORM,1 PARAMETER ADDRESS TO B1
 00000 1           LDAQ,I   0,1       X TO AQ
 P00024 3          AZJ,LT   INIT      INITIALIZE IF X LT ZERO

               IF X GE ZERO ON CALL, GENERATE A NEW RANDOM NUMBER.

 P00042 0          LDAQ     Y         NEWY=(A*OLDY+2*C)MOD2**36
 P00044 0          MUAQ     A
 00000 3           EAQ
 07777 2           ANA      7777B
 P00046 0          ADAQ     C2
 07777 2           ANA      7777B
 P00042 0  CONT    STAQ     Y         SAVE Y FOR NEXT TIME

               CONVERT THE 36 BIT NUMBER IN AQ TO A FLOATING POINT FRACTION.

 02013 2           SCAQ     2013B,2   SCALE AQ,BIASED EXPONENT TO B2
 P00022 0          AZJ,EQ   RETURN    ZERO IS A SPECIAL CASE
 02000 2           ISG      2000B,2   TEST FOR NON-NEGATIVE EXPONENT
 77776 2           INI      -1,2      ADJUST BIAS IF NEGATIVE
 00031 0           SHAQ     25        MERGE FRACTION AND EXPONENT
 40000 2           AIA      2
 00014 0           SHAQ     12        AQ IS NOW A FLOATING POINT FRACTION

               STORE AQ IN X, AND RETURN TO CALLING PROGRAM.

 00000 1  RETURN   STAQ,I   0,1       STORE AQ IN X
```

```
 00001 1              UJP       1,1        RETURN TO PARAMETER ADDRESS + 1

                IF X LT ZERO ON CALL, CONVERT -X TO FIXED POINT AND USE IT TO
                INITIALIZE THE RANDOM NUMBER GENERATOR.

 77777 0   INIT      XOA,S     77777B     NEGATE AQ
 77777 1             XOQ,S     77777B
 00044 0             SHAQ      36         BIASED EXPONENT TO B2
 00000 2             TAI       2
 03777 2             ANI       3777B,2
 00014 0             SHAQ      12         FRACTION TO AQ
 07777 2             ANA       7777B
 02001 2             ISG       2001B,2    SKIP IF EXPONENT GE 1
 01735 2             ISG       1735B,2    SKIP IF EXPONENT GE -34
P00051 0             LDAQ      ZERO       FORCE ZERO IF EXPONENT OUT OF BOUNDS
 01777 2             ISG       1777B,2    SKIP IF EXPONENT NON-NEGATIVE
 76000 2             SHAQ      -1777B,2   EXPONENT IS SHIFT COUNT, IF NEGATIVE
 77776 1             ANQ,S     77776B     CLEAR LSB TO RETAIN 35 BITS
P00012 0             UJP       CONT       USE AQ FOR NEW Y IN MAIN LOOP

                CONSTANTS AND VARIBLES

)00        Y         OCT       0,0
)00
)32        A         OCT       3432,77244615   THIS IS 5**15
)15
)41        C2        OCT       1541,45427232   THIS IS 2*7261067065
)32
)00        ZERO      OCT       0,0
)00

                     END

                NUMBER OF LINES WITH DIAGNOSTICS         0
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